EAST Search history

L Number	Hits	Search Text	DB	Time stamp
1	85	"back facet monitor"	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 18:17
4	17	"back facet monitor" and (DC bias) near3 voltage	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 18:18
5	3	"back facet monitor" same(DC bias) near3 voltage	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 18:18
6	3	"back facet monitor" same (DC bias) near3 voltage	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 18:33
7	24	"back facet" with feedback and optical and (RF "radio frequency")	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 18:41
-	4	896211.ap.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 14:41
-	260	schemmann.in.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 14:41
-	1	schemmann-marcel.in.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 14:41
-	53	mutalik.in.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 14:45
-	3	871216.ap.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 14:59
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-	179	398/115,116,141,156,158,159,162,182,183,192,193,194,195,197,199,200,201,208,209,21 and (RF "radio frequency") and feedback and (adjust$4 stabiliz$5 compensat$3)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:04

-	48	398/115,116,141,156,158,159,162,182,183,192,1[illegible]4,195,1[illegible]201,208,209,21 and (RF "radio frequency") with (adjust$4 stabiliz$5 compensat$3) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:23
-	2	5,161,044.pn.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:20
-	293	(RF "radio frequency") with (adjust$4 stabiliz$5 compensat$3 linear$7) and feedback and (CATV (cable with television))	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:24
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-	134	(RF "radio frequency") with (adjust$4 stabiliz$5 compensat$3 linear$7) and feedback and (CATV (cable with television)) and temperature and transmit$4 and receiv$3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:24
-	80	(RF "radio frequency") with (stabiliz$5 compensat$3 linear$7) and feedback and (CATV (cable with television)) and temperature and transmit$4 and receiv$3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:25
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-	67	(RF "radio frequency") with (stab$7 compensat$3 linear$7) and feedback and (CATV (cable with television)).bsum. and temperature and transmit$4 and receiv$3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:38
-	41	optical and (RF "radio frequency") with (stab$7 compensat$3 linear$7) and feedback and (CATV (cable with television)).bsum. and temperature and transmit$4 and receiv$3	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:49

-	397	optical and (RF "radio frequency") near3 stab$7	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:49
-	338	optical and (RF "radio frequency") near3 (stable stabiliz$5)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:49
-	400	optical and (RF "radio frequency") near3 (stable stabili$6)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:50
-	22	optical and (RF "radio frequency") near3 (stable stabili$6) and (CATV (cable near1 television))	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 16:25
-	216	optical and (RF "radio frequency") with transmitter and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 16:26
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-	2	5963570.uref.	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 16:35
-	1	optical and (omv (optical near1 modulation near1 voltage)) same receiver	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 16:42
-	85	back near1 facet with feedback and optical	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 16:42
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-	18	optical with (RF "radio frequency") with oscillat$3 and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 11:45
-	248	optical and (RF "radio frequency") and oscillat$3 and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 11:46
-	100	optical and (RF "radio frequency") and oscillat$3 with (dither$3 modulat$3) and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 11:47
-	146	optical and (RF "radio frequency") and oscillat$3 with (dither$3 modulat$3 tone) and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 13:37
-	211	optical and (RF "radio frequency") and direct$2 with modulat$3 and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 13:38
-	81	optical and (RF "radio frequency") and direct$2 with modulat$3 with laser and (CATV (cable near1 television)) and feedback	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/05 14:23
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-	142	(RF "radio frequency") with (adjust$4 stabiliz$5 compensat$3 linear$7) and feedback and (CATV (cable with television)) and temperature	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2004/03/04 15:24
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US006687466B1

(12) United States Patent
Chiappetta

(10) **Patent No.:** **US 6,687,466 B1**
(45) **Date of Patent:** **Feb. 3, 2004**

(54) **DYNAMIC DISTORTION CONTROL**

(75) Inventor: **Joseph F. Chiappetta**, Shelton, CT (US)

(73) Assignee: **ADC Telecommunications, Inc.**, Eden Prairie, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/478,644**

(22) Filed: **Jan. 6, 2000**

(51) **Int. Cl.**[7] **H04B 10/04**

(52) **U.S. Cl.** **398/193**; 398/194; 375/296; 330/149

(58) **Field of Search** 359/110, 161, 359/187; 375/296; 398/33, 94, 193–194, 197; 330/149

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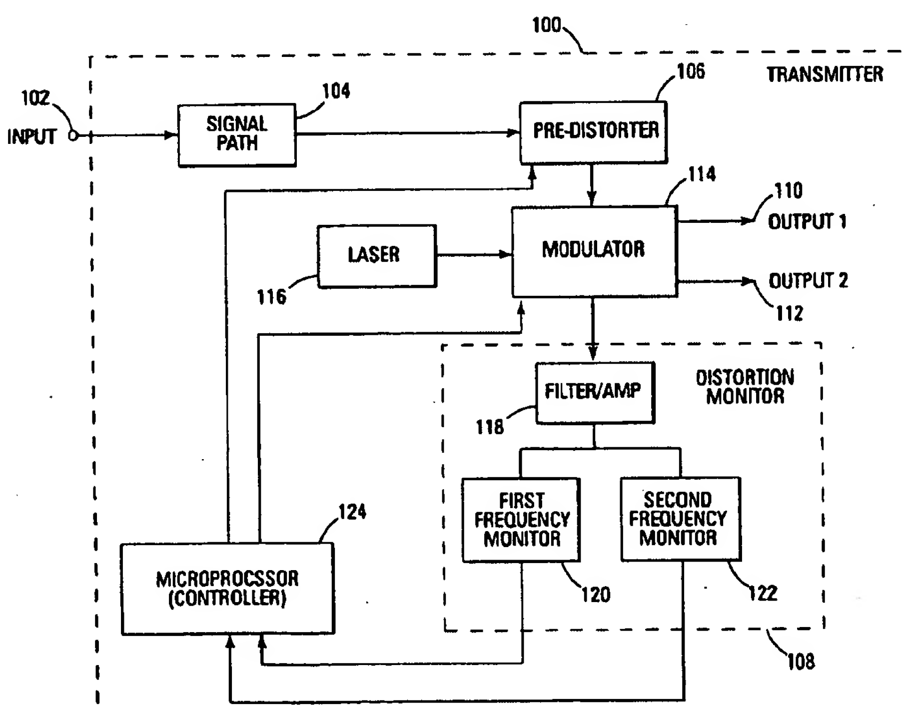
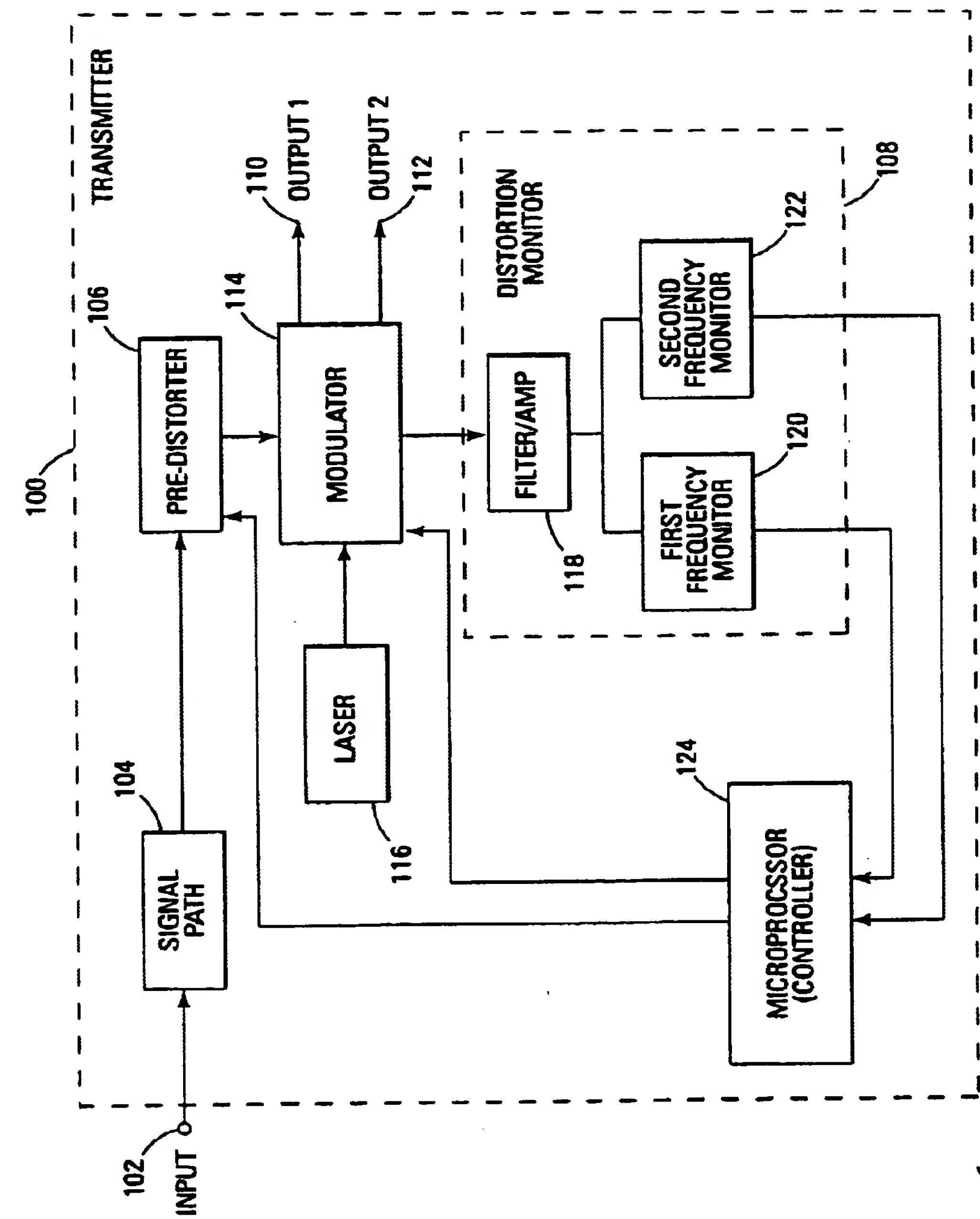
Primary Examiner—Kinfe-Michael Negash
(74) *Attorney, Agent, or Firm*—Fogg and Associates, LLC; Laura A. Ryan; David N. Fogg

(57) **ABSTRACT**

A distortion monitor for a non-linear device is provided. The control circuit includes an input coupleable to receive a signal from the non-linear device and a first frequency monitor coupled to the input. The frequency monitor monitors the level of one of even and odd order distortion at a first frequency and creates a first signal indicative of the level of the distortion without the use of a pilot tone.

30 Claims, 5 Drawing Sheets

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100
102
INPUT
104
SIGNAL PATH
106
PRE-DISTORTER
114
MODULATOR
110
OUTPUT 1
OUTPUT 2
112
LASER
116
DISTORTION MONITOR
108
FILTER/AMP
118
FIRST FREQUENCY MONITOR
120
SECOND FREQUENCY MONITOR
122
124
MICROPROCSSOR (CONTROLLER)

Fig. 1

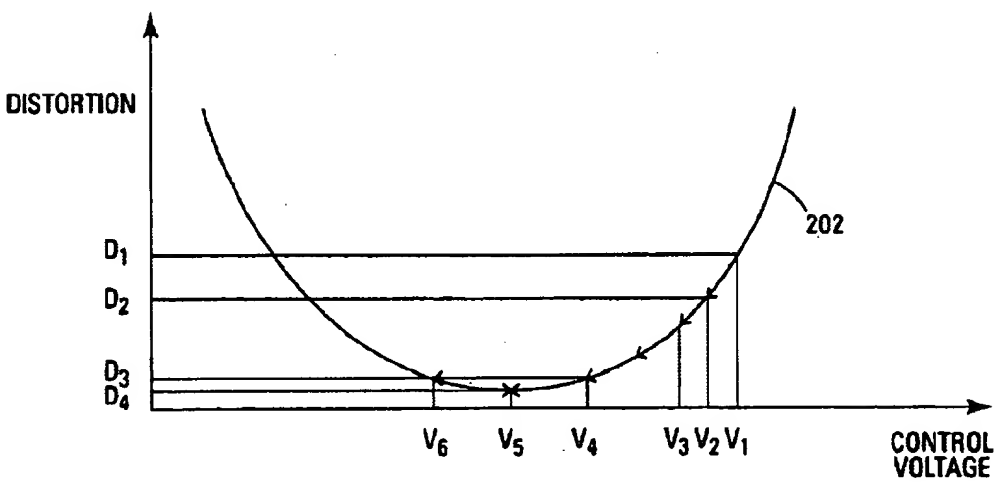

Fig. 2

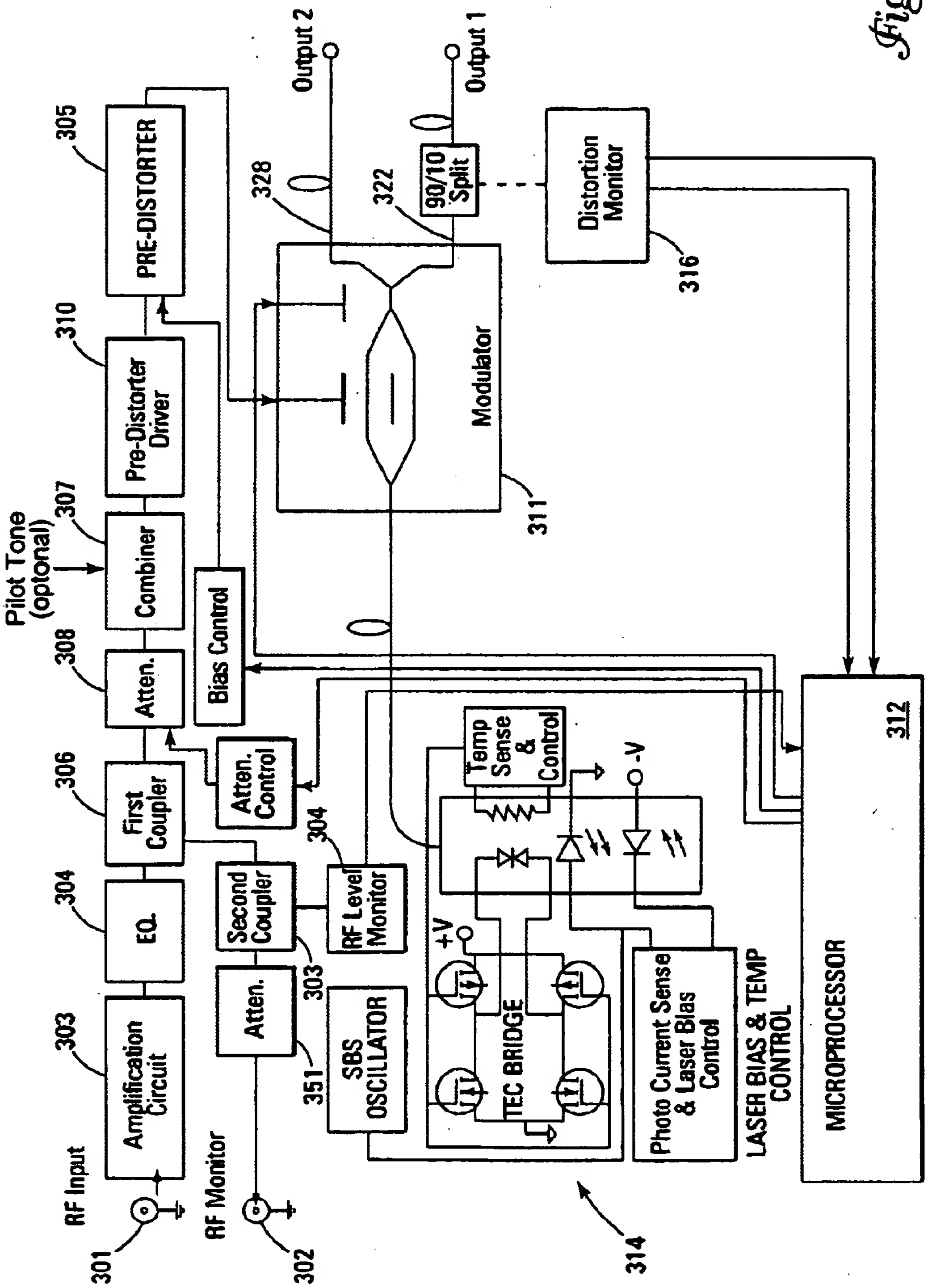
RF Input
301
RF Monitor
302
Amplification Circuit
303
EQ.
304
First Coupler
306
Atten.
308
Combiner
307
Pilot Tone (optonal)
Pre-Distorter Driver
310
PRE-DISTORTER
305
Bias Control
Atten. Control
Second Coupler
303
Atten.
351
RF Level Monitor
304
SBS OSCILLATOR
TEC BRIDGE
+V
-V
Temp Sense & Control
Photo Current Sense & Laser Bias Control
LASER BIAS & TEMP CONTROL
314
Modulator
311
328
322
Output 2
Output 1
90/10 Split
Distortion Monitor
316
MICROPROCESSOR
312

Fig. 3

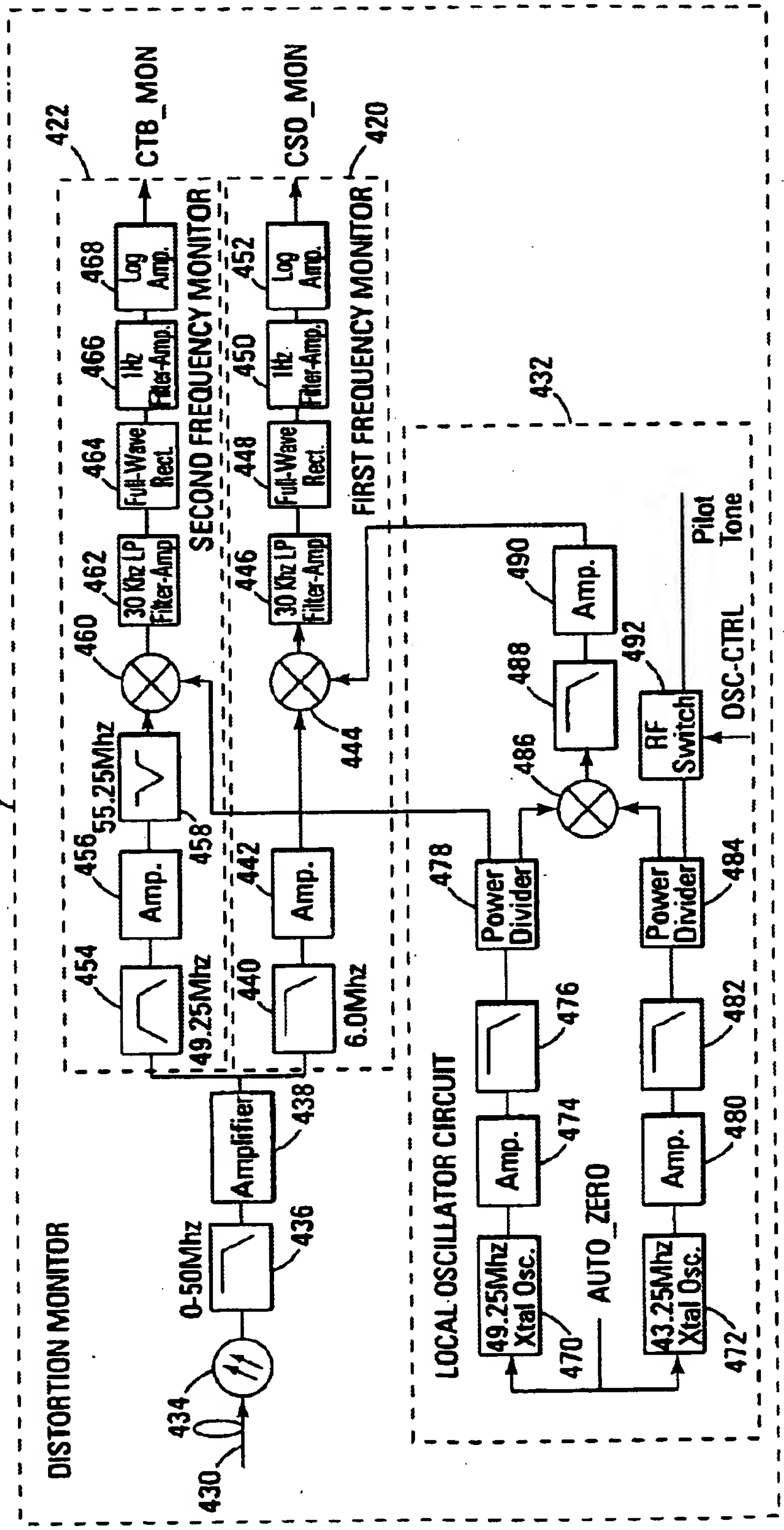
DISTORTION MONITOR
408
430
434
0-50Mhz
436
Amplifier
438
SECOND FREQUENCY MONITOR
422
454
49.25Mhz
456
Amp.
458
55.25Mhz
460
462
30 Khz LP Filter-Amp
464
Full-Wave Rect.
466
1Hz Filter-Amp.
468
Log Amp.
CTB_MON
FIRST FREQUENCY MONITOR
420
440
6.0Mhz
442
Amp.
444
446
30 Khz LP Filter-Amp
448
Full-Wave Rect.
450
1Hz Filter-Amp.
452
Log Amp.
CSO_MON
LOCAL OSCILLATOR CIRCUIT
432
470
49.25Mhz Xtal Osc.
474
Amp.
476
478
Power Divider
AUTO_ZERO
472
43.25Mhz Xtal Osc.
480
Amp.
482
484
Power Divider
486
488
490
Amp.
492
RF Switch
OSC-CTRL
Pilot Tone

Fig. 4

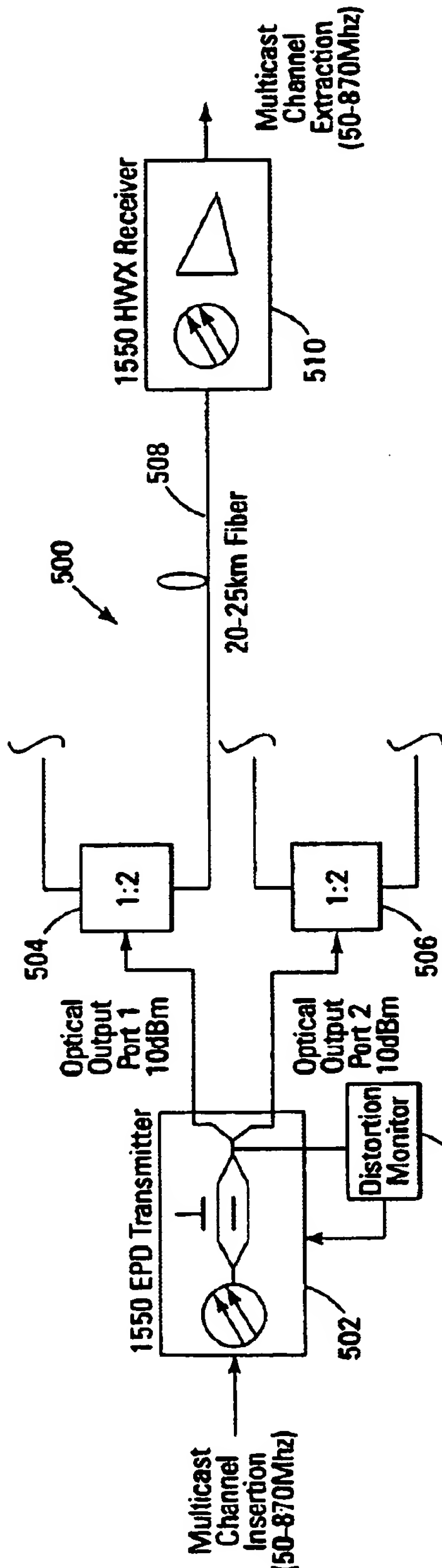
Multicast Channel Extraction (50-870Mhz)
1550 HWX Receiver
510
508
500
20-25km Fiber
504
1:2
1:2
506
Optical Output Port 1 10dBm
Optical Output Port 2 10dBm
1550 EPD Transmitter
Distortion Monitor
503
502
Multicast Channel Insertion (50-870Mhz)

Fig. 5

DYNAMIC DISTORTION CONTROL

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to commonly assigned, co-pending application Ser. No. 09/479,298, entitled "PRE-DISTORTER WITH NON-MAGNETIC COMPONENTS FOR A NON-LINEAR DEVICE," filed on the same date as the present application. The '739 Application is incorporated herein by reference.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to the field of telecommunications and, in particular, to dynamic distortion control.

BACKGROUND

Due to the increased demand for higher capacity in voice, data and video transmission the communications market is expanding. In particular optical fiber communications technology has been developing in response to the market requirements. Optical transmitters are one type of fiber communications technology that is evolving to meet the increased demand.

Optical transmitters that utilize pre-distortion devices for distortion cancellation are well known. Typically, these transmitters are designed around a Mach-Zehnder optical modulator. The modulator is fed from a high power laser. The laser operates in the cool white mode and provides the "light source" that has its intensity or amplitude modulated in the Mach-Zehnder device.

The optical modulation is accomplished by feeding a radio frequency (RF) modulating signal to the appropriate port of the modulator. In this way RF amplitude modulation is converted to optical amplitude modulation.

A detrimental characteristic of the optical modulator is that its optical output/RF input transfer characteristic is very non-linear; it is sinusoidal in nature. Consequently for a large modulation index (the ratio of the peak variation actually used to the maximum design variation (e.g., that variation whereby the instantaneous amplitude of the modulated carrier reaches zero) severe odd order distortion is generated. In order to overcome this distortion an external means is required to compensate for the nonlinear transfer function.

Pre-distorters have been used to in the past to minimize odd order distortions generated in the modulator. These odd order distortions are reduced by a circuit that generates its own RF distortions and then injects them into the modulator out of phase with those that are generated by the modulator. The pre-distorters have been limited in their operating bandwidth and in their absolute distortion cancellation due to the use of magnetic components used to achieve the phase inversions that operate to cancel the distortion products.

Typically, an optical transmitter also includes some circuitry to monitor the distortions introduced in the transmitter. It has been common practice to use one or more auxiliary pilot tones along with the many main carrier signals and to monitor distortion products from the pilot tones to asses the operation of the transmitter. One drawback of this technique is that it uses additional, unwanted signals. Further, these signals produce distortion products with very low energy, making the signals difficult to pick up.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an improved mechanism to control distortion in a non-linear device, e.g., an optical transmitter.

SUMMARY

The above mentioned problems with non-linear devices and other problems are addressed by the present invention and will be understood by reading and studying the following specification. A non-linear device is provided which uses a distortion monitor to monitor distortion products generated at least in part by transmission of carrier signals to control the operation of the non-linear device.

In particular, an illustrative embodiment of the present invention includes a distortion monitor for a non-linear device, e.g., an optical transmitter. The distortion monitor includes an input coupleable to receive a signal from the non-linear device and a first frequency monitor coupled to the input. The frequency monitor monitors the level of one of even and odd order distortion at a first frequency and creates a first signal indicative of the level of the distortion without the use of a pilot tone.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an embodiment of a transmitter including a distortion monitor according to the teachings of the present invention.

FIG. 2 is a graph that illustrates an embodiment of a process for generating a control voltage to control the distortion in a modulator according to the teachings of the present invention.

FIG. 3 is a block diagram of another embodiment of a transmitter including a distortion monitor according to the teachings of the present invention.

FIG. 4 is a block diagram of an embodiment of a distortion monitor according to the teachings of the present invention.

FIG. 5 is a block diagram of an embodiment of a system including a transmitter with a distortion monitor according to the teachings of the present invention.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings which form a part of the specification. The drawings show, and the detailed description describes, by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be used and logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

FIG. 1 is a block diagram of an embodiment of a transmitter, indicated generally at **100**, including a distortion monitor **108** according to the teachings of the present invention. Transmitter **100** receives RF input signals at input **102** and produces optical outputs at **110** and **112**. In other embodiments a single output or a plurality of outputs are provided. The RF input signals of transmitter **100** pass through signal path **104**, pre-distorter **106**, and modulator **114**. In one embodiment, signal path **104** includes at least one amplifier, and an equalizer. In other embodiments, signal path **104** also includes an attenuator and other circuits to prepare the RF signal for transmission over an optical fiber.

Transmitter **100** converts the electrical, RF signals received at input **102** to optical signals produced by laser **116** and optical modulator **114**. In one embodiment, optical modulator **114** comprises a non-linear modulator such as a Mach-Zehnder modulator. Laser **116** is coupled to modulator **114** to create the optical signals at outputs **110** and **112**. Unfortunately non-linear modulators introduce distortion in the optical signal, e.g., even order and odd order distortion, produced at outputs **110** and **112**. Thus, transmitter **100** includes circuitry that is used to compensate for these distortions produced by optical modulator **114**.

To provide this compensation, transmitter **100** includes pre-distorter **106**. In one embodiment, pre-distorter **106** is constructed according to the teachings of the '739 application. In other embodiments, pre-distorter **106** is constructed using more conventional pre-distorter circuits incorporating magnetic phase inversion circuits. Pre-distorter **106** is coupled between signal path **104** and modulator **114**. Pre-distorter **106** adds distortion to the RF signals from signal path **104** in order to compensate for the distortion introduced by modulator **114**.

Transmitter **100** also includes circuitry that selectively adjusts the operation of one of pre-distorter **106** and modulator **114** based on distortions detected in the output of modulator **114**. Distortion monitor **108** is coupled to receive the output of modulator **114** at filter/amplifier **118**. Filter/amplifier **118** is coupled to first and second frequency monitors **120** and **122**, respectively. First and second frequency monitors **120** and **122** provide signals to microprocessor or controller **124**. Microprocessor **124** uses a control algorithm, such as the algorithm described below with respect to FIG. **2**, to selectively generate signals for pre-distorter **106** and modulator **114**. In one embodiment, these control signals from microprocessor **124** are used to control a bias voltage for amplifiers in pre-distorter **106** and a DC bias voltage for modulator **114**.

First and second frequency monitors **120** and **122** are tuned to monitor selected frequencies for potential distortion products at these selected frequencies. In one embodiment, these distortion products monitored by first and second frequency monitors **120** and **122** are generated based on actual signals received at input **102** and are not generated based on pilot tones. In another embodiment, one of the first and second frequency monitors **120** and **122** monitors signals generated, at least in part, based on a pilot tone.

In one embodiment, transmitter **100** operates with cable television (CATV) radio frequency (RF) input carrier frequencies. In a typical system, these frequencies are spaced apart at nominally 6.0 MHZ increments. The actual 6 MHZ frequency difference between carriers depends on the absolute frequency accuracy of each individual carrier. This carrier accuracy is such that the difference of each carrier from the nominal 6 MHZ is typically within zero to less than 30 kHz. Modulator **114** converts these RF carrier signals to their corresponding optical counterparts.

In one embodiment, first frequency monitor **120** monitors even-order distortions and second frequency monitor **122** monitors odd-order distortions. One way in which the even-order distortions manifest themselves follows the $f_n - f_{n+1}$ rule whereby an approximate 6 MHZ distortion product is generated for every pair of RF frequencies that are spaced apart by 6 MHZ. This results in many distortion products in the frequency spectrum at outputs **110** and **112** of transmitter **100**. First frequency monitor **120** detects these even-order distortion products within the nominal 6 MHZ±30 kHz frequency range. This provides a measure of the even-order distortion of transmitter **100**.

Similarly, one way in which odd-order distortions manifest themselves follows the $f_1 - f_2 - f_3$ rule whereby a 49.25 MHZ distortion product is generated for many combinations of RF frequencies in a multi-channel format. Again, this results in many distortion products in the frequency spectrum at outputs **110** and **112** of transmitter **100**. Second frequency monitor **122** detects these odd-order distortion products within the nominal 49.25 MHZ±30 kHz frequency range. This provides a measure of the odd-order distortion of transmitter **100**.

In another embodiment, distortion monitor **108** monitors distortion products generated by a pilot tone provided to pre-distorter **106**. In this embodiment, odd-order distortions manifest themselves following the $f_{n+1} - f_n + f_m$ rule whereby a 49.25 MHZ distortion product is again generated for every pair of RF frequencies that are 6 MHZ spaced when mixed with a single 43.25 MHZ pilot signal (f_m). Again, second frequency monitor **122** detects these distortion products within the nominal 49.25 MHZ±30 kHz frequency range. This also provides a measure of the odd-order distortion of transmitter **100**, with the use of a single pilot tone.

In operation, transmitter **100** receives electrical RF signals at input **102** and produces optical signals at outputs **110** and **112**. The signals from input **102** are amplified and prepared for pre-distorter **106** at signal path **104**. Pre-distorter **106** adds a selected distortion to the signals from signal path **104**. In one embodiment, pre-distorter **106** adds odd-order distortions that are inversely related to the expected distortions for modulator **114**. Laser **116** and modulator **114** combine to pass the signals from pre-distorter **106** to outputs **110** and **112**.

The amount of distortion in outputs **110** and **112** of transmitter **100** is controlled by a feedback loop that monitors the distortion in the outputs **110** and **112** and provides control signals to pre-distorter **106** and modulator **114**. This feedback loop includes distortion monitor **108**. Distortion monitor **108** receives the output of modulator **114** at filter/amplifier **118**. This signal is further provided to first and second frequency monitors **120** and **122**, respectively. First frequency monitor **120**, in one embodiment, monitors energy at a first selected frequency, e.g., 6 MHZ, that relates to even-order distortion products. Similarly, second frequency monitor **122** monitors, in one embodiment, energy at a second selected frequency, e.g., 49.25 MHZ, that relates to odd-order distortion products. It is noted that in some embodiments a pilot tone is used to generate at least some of the odd-order distortion products detected by second frequency monitor **122**.

Distortion monitor **108** provides two output signals to microprocessor **124**. First frequency monitor **120** provides a signal that is related to the amount of even order distortion in the output of modulator **114**. Second frequency monitor **122** provides a signal that is related to the amount of odd-order distortion in the output of modulator **114**.

Microprocessor **124** uses the signals from distortion monitor **108** to selectively create control signals for pre-distorter **106** and modulator **114**. For example, microprocessor **124** selectively generates a control signal for pre-distorter **106** that controls at least one bias current for an amplifier in pre-distorter **106**. Microprocessor **124** also selectively generates a second control signal for modulator **114** that controls a DC bias voltage for modulator **114**.

Microprocessor **124** implements a control algorithm depicted graphically in FIG. **2** to generate these control signals for pre-distorter **106** and modulator **114**. For purposes of simplicity, the graph of FIG. **2** is described in terms

of generating the control signal for modulator **114**. However, it is understood, that a similar routine is used to generate a control voltage for pre-distorter **106**.

At the beginning of the algorithm, microprocessor **124** outputs an initial value labeled as V_1 in FIG. **2**. This voltage is a preset value that presupposes an acceptable setting for modulator **114**. Due to temperature and component aging, the setting will not normally be the final setting established by microprocessor **124**. At the initial setting, V_1, distortion monitor **108** provides a signal indicating to microprocessor **124** that distortion level is D_1. Because this is a single measurement, the algorithm implemented by microprocessor **124** does not know where this point lies on curve **202**. Thus, microprocessor **124** adjusts the control voltage to a value V_2 that is higher or lower than V_1. Microprocessor **124** than receives an updated distortion reading, D_2, from distortion monitor **108**. In FIG. **2**, distortion level D_2 is depicted as being lower than the distortion level D_1. Thus microprocessor **124** determines that the control voltage was correctly lowered to reduce the distortion level and again lowers the control voltage to voltage V_3. It is noted that when lowering the control voltage results in a higher distortion level, microprocessor **124** raises the control voltage to try to move the distortion level lower. Once microprocessor **124** has determined that the control voltage is moving in the correct direction, microprocessor **124** continues to modify the control voltage until the change in the control voltage results in increasing distortion such as the situation depicted with voltage V_6. At this point, microprocessor **124** returns the control voltage to the level preceding level that increased distortion, e.g., V_5. Microprocessor **124** further continuously uses this process to output control voltages as changes in the distortion level are detected in order to maintain a control voltage that keeps distortion at a relative minimum.

FIG. **3** is a block diagram of another embodiment of a transmitter, indicated generally at **300**, including a distortion monitor **316** according to the teachings of the present invention. The transmitter receives RF input signals at RF input **301** and the signals are fed to an amplification circuit **303** where the signals are amplified and fed to an equalizer **304**. The equalizer **304** receives the amplified signals equalizes the signals and feeds them to a first coupler **306**. The first coupler **306** samples the equalized signals and feeds the sampled signals to a second coupler **303** which splits the sampled signals for transmission to an attenuator **351** and an internal RF level monitor **304**. The attenuator **351** receives the split signals, attenuates them and feeds the signals to an external RF monitor through RF output **302**. The internal RF level monitor **304** receives the split signals and feeds the signals to a microprocessor **312** for monitoring and control.

In addition, the coupler **306** feeds the equalized signals to an attenuator **308**. The attenuator **308** receives the equalized signals and attenuates the signals. In one embodiment the attenuator feeds the attenuated signals to a pre-distorter driver **310**. In other embodiments the attenuator **308** feeds the attenuated signals to a combiner **307** and the signals are then fed to a pre-distorter driver **310**. The combiner **307** adds a pilot tone as detectable distortion to the attenuated signals. The pre-distorter driver **310** receives the signals, amplifies the signals and feeds the amplified signals to a pre-distorter **305**.

The pre-distorter **305** generates odd order distortions for input to a modulator **311**. In one embodiment the modulator **311** is an optical modulator and in another embodiment the modulator is a Mach Zehnder modulator. The odd order distortions generated by the pre-distorter **305** are complimentary to distortions generated by the modulator **311**. The complimentary signals are substantially equal in magnitude to the distortions for modulator **311** but are 180 degrees out of phase with the distortions of modulator **311**. The pre-distorter **305** feeds the signals with the complimentary distortions to the modulator **311**. The modulator **311** is coupled to a laser bias and temperature control device **314** which provides a light source for modulation by the modulator **311**. The modulator **311** receives the RF signals and the light source and generates modulated optical outputs **320** and **322**. The modulator is nonlinear and produces odd-order distortions in addition to the optical outputs **320** and **322**. For a large modulation index the odd-order distortions are severe. The complimentary odd order distortions created by the pre-distorter **305** substantially reduce the distortions created by the modulator **311**.

In this embodiment a distortion monitor **316** monitors the output signal **322** of the modulator **311** for the presence of distortion products at one or more frequencies, e.g., even and odd order distortion products. The distortion monitor **316** receives the output of modulator **311** and provides the monitored distortion levels to the microprocessor **312** to generate control signals. The microprocessor **312** also receives signals from the RF level monitor **304**. The microprocessor **312** provides output signals based on input signals from RF level monitor **304** to an attenuation control device **305** to control the operation of attenuator **308**.

In this embodiment the transmitter **300** is a 1550 nm wavelength external modulation transmitter. In other embodiments, transmitter **300** comprises an optical transmitter that uses direct modulation. In further embodiments, other wavelengths are used.

FIG. **4** is a block diagram of an embodiment of a distortion monitor, indicated generally at **408**, according to the teachings of the present invention. Distortion monitor **408** monitors the output of an optical modulator, such as a Mach Zehnder modulator, to determine the presence of even- and odd-order distortion products. Distortion monitor **408** includes first frequency monitor **420** and second frequency monitor **422**. First and second frequency monitors **420** and **422** each include a mixer that is controlled by local oscillator circuits **432**. First frequency monitor **420** is tuned to identify distortion products located in the 6 MHZ range. Similarly, second frequency monitor **422** is tuned to identify distortion products located in the 49.25 MHZ range.

Distortion monitor **408** includes input **430** that is coupled to circuitry that prepares the output of an optical modulator for input to the first and second frequency monitors **420** and **422**. The signals received at input **430** are detected by photo diode **434**. Photo diode **434** is coupled to low pass filter **436** to filter out as much of the carrier frequency energy above 50 MHZ as possible. This reduces the load on the front end of distortion monitor **408** since the carriers are typically 60 to 70 dB greater than the distortion products. Low pass filter **436** provides its signal to amplifier **438**. Amplifier **438** provides, for example, 20 dB of distortion gain and establishes the signal-to-noise ratio of distortion monitor **408**.

The output of amplifier **438** is split into two paths; a first path passing through first frequency monitor **420** and a second path passing through second frequency monitor **422**. In both paths, the output of amplifier **438** is down-converted to low audio frequency "base-band" signals by mixing the output of amplifier **438** with 6 MHZ and 49.25 MHZ signals, respectively, from local oscillator circuit **432** using double-balanced mixers. The base-band signals are further processed to produce output signals indicative of the distortion products found in the output of the optical modulator.

First frequency monitor **420** monitors distortion products located at 6 MHZ±30 kHz. First frequency monitor **420** includes low pass filter **440** and amplifier **442** that are coupled in series between amplifier **438** and mixer **444**. Low pass filter **440** rejects signals above 6 MHZ. Amplifier **442** further boosts the level of the distortion products in this frequency range. Mixer **444** down-converts the distortion products to base-band.

The output of mixer **444** is coupled to the series combination of filter/amplifier **446**, full wave rectifier **448**, filter/amplifier **450**, and log amplifier **452**. In one embodiment, filter/amplifier **446** has a 30 kHz bandwidth to simultaneously limit the noise power and also allow for as much distortion energy as possible to drive full wave rectifier **448**. In one embodiment, filter/amplifier **450** comprises a 1 Hz active filter that filters the output of full wave rectifier **448**. Log amplifier **452** increases the operating dynamic range of distortion monitor **408** by compressing the normally large signal swing that would result from using a linear high gain amplifier. The final DC output level of log amplifier **452** represents a measure of the even-order distortion products of the optical modulator. Small DC levels at the output of log amplifier **452** represents lower levels of distortion products.

Second frequency monitor **422** monitors distortion products located at 49.25 MHZ±30 kHz. Second frequency monitor **422** includes bandpass filter **454**, amplifier **456**, and notch filter **458** that are coupled in series between amplifier **438** and mixer **460**. The pass band of bandpass filter **454** includes the 49.25 MHZ frequency. Amplifier **456** further boosts the level of the distortion products in this frequency range. In one embodiment, notch filter **458** is included to suppress carriers above the 49.25 MHZ frequency, e.g., the 55.25 MHZ carrier, in order to pass the 49.25 MHZ distortion products. Mixer **460** down-converts the distortion products to base-band.

The output of mixer **460** is coupled to the series combination of filter/amplifier **462**, full wave rectifier **464**, filter/amplifier **466**, and log amplifier **468**. In one embodiment, filter/amplifier **462** has a 30 kHz bandwidth to simultaneously limit the noise power and also allow for as much distortion energy as possible to drive full wave rectifier **464**. In one embodiment, filter/amplifier **466** comprises a 1 Hz active filter that filters the output of full wave rectifier **464**. Log amplifier **468** increases the operating dynamic range of distortion monitor **408** by compressing the normally large signal swing that would result from using a linear high gain amplifier. The final DC output level of log amplifier **468** represents a measure of the odd-order distortion products of the optical modulator. Small DC levels at the output of log amplifier **452** represents lower levels of distortion products.

Local oscillator circuit **432** provides inputs to mixers **444** and **460** of first and second frequency monitors **420** and **422**, respectively. Local oscillator circuit **432** includes first and second crystal oscillators **470** and **472**. In one embodiment, the first crystal oscillator **470** comprises a 49.25 MHZ oscillator and second crystal oscillator **472** comprises a 43.25 MHZ crystal oscillator. First and second crystal oscillators **470** and **472** receive a control signal labeled AUTO_ZERO that is used to turn the oscillators on or off.

First crystal oscillator **470** generates the local oscillator signal for mixer **460**. First crystal oscillator **470** includes an output that is coupled through amplifier **474**, filter **476**, and power divider **478** to an input of mixer **460**. This input of mixer **460** receives a 49.25 MHZ local oscillator signal.

First and second crystal oscillators **470** and **472** combine to provide a local oscillator input for mixer **444**. Second crystal oscillator **472** includes an output that is coupled to the series combination of amplifier **480**, filter **482**, and power divider **484**. Power dividers **478** and **484** each provide an input to mixer **486**. Mixer **486** provides a local oscillator signal, e.g., a 6 MHZ signal, to mixer **444** through filter **488** and amplifier **490**.

In one embodiment, second crystal oscillator **472** also is used to provide a pilot tone to be injected into the signal provided to the modulator. This pilot tone is taken from power divider **484** and selectively provided to the modulator by RF switch **492** under the control of a signal labeled OSC-CTRL.

FIG. **5** is a block diagram of an embodiment of a system, indicated generally at **500**, including transmitter **502** with distortion monitor **503** according to the teachings of the present invention. In one embodiment, system **500** transports cable television (CATV) channels, e.g., 80 to 112 channels, between two distant locations via an optical link. The optical link is preferred over a coaxial copper cable link because the fiber optic link provides a wider bandwidth and lower loss.

System **500** includes transmitter **502** that is coupled to receive multicast channel insertion, e.g., RF signals between 50 and 870 MHZ. Transmitter **502** comprises, for example, the transmitter shown in FIG. **1** or **3** above. Transmitter **502** is coupled to distortion monitor **503** which monitors distortion products in the output of transmitter **502** and provides control signals to transmitter **502** in order to reduce distortion products in its output. Distortion monitor **503**, in one embodiment, is constructed as shown and described above with respect to FIGS. **1**, **2**, **3**, and **4**.

Transmitter **502** provides output to splitters **504** and **506** to increase the number of paths that can be supported by transmitter **502**. Each path supported by transmitter **502** includes a fiber-optic cable **508**. In one embodiment, fiber-optic cable **508** has a length from 20 to 25 kilometers. Fiber-optic cable **508** is terminated by a receiver **510** that converts the optical signal back to an electrical signal for transmission over coaxial cable.

CONCLUSION

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. For example, the distortion monitor can monitor distortion products at any appropriate frequency and is not limited to distortion products at 6 MHZ and 49.25 MHZ. Rather, the specific frequency is chosen to be a frequency outside the channel raster alignment at a frequency representative of even or odd order distortions. Further, the components in the first and second frequency monitors can be adjusted as necessary to allow for monitoring distortion products at selected frequencies. Further, any appropriate local oscillator arrangement can be used to create the local oscillator signals for the first and second frequency monitors. Further, in some embodiments, only one frequency monitor is provided, e.g., to monitor even or odd order distortion at a single frequency. In other embodiments, the signals from the distortion monitor are provided as output for use in manual control of the non-linear device. Further, in other embodiments, the distortion monitor is used with non-linear devices other than an optical transmitter.

What is claimed is:

1. A distortion monitor for a non-linear device, the distortion monitor comprising:

an input coupleable to receive a signal from the non-linear device; and

a frequency monitor, coupled to the input, that monitors the level of one of even and odd order distortion at a first frequency and that creates a signal indicative of the level of the distortion without the use of a pilot tone.

2. The distortion monitor of claim 1, wherein the non-linear device comprises an optical transmitter.

3. The distortion monitor of claim 1, and further including:

a pre-distorter coupled to the non-linear device; and

a controller, coupled to the frequency monitor to receive the first and second signals and to selectively create at least one control signal for one of the non-linear device and the pre-distorter.

4. The distortion monitor of claim 3, wherein the controller generates first and second control signals, wherein the first control signal controls a bias voltage for the pre-distorter and the second control signal controls a DC bias for the non-linear device.

5. The distortion monitor of claim 1, wherein the frequency monitor includes at least one filter and a mixer that select the frequency and down convert the frequency to base-band.

6. The distortion monitor of claim 1, wherein the frequency monitor monitors distortion products at a frequency outside the channel raster alignment that are representative of even order distortion.

7. The distortion monitor of claim 1, wherein the frequency monitor monitors distortion products at a frequency outside the channel raster alignment, wherein the frequency is representative of odd order distortion.

8. A control circuit for dynamic distortion control in a non-linear device, the control circuit comprising:

an input coupleable to receive a signal from the non-linear device;

a frequency monitor, coupled to the input, that monitors the level of odd order distortion at a frequency and that creates a signal indicative of the level of the distortion without the use of a pilot tone; and

a controller, coupled to the frequency monitor to receive the first and second signals and to selectively create at least one control signal to control the non-linear device.

9. The control circuit of claim 8, wherein the non-linear device comprises an optical transmitter.

10. The control circuit of claim 8, and further including a pre-distorter coupled to the non-linear device and controlled by the controller.

11. The control circuit of claim 10, wherein the controller generates first and second control signals, wherein the first control signal controls a bias voltage for the pre-distorter and the second control signal controls a DC bias for the non-linear device.

12. The control circuit of claim 8, wherein the frequency monitor includes at least one filter and a mixer that selects the frequency and down converts the frequency to base-band.

13. The control circuit of claim 8, wherein the frequency monitor monitors first distortion products at a frequency outside the channel raster alignment, wherein the frequency is representative of odd order distortion.

14. A control circuit for dynamic distortion control in a non-linear device, the control circuit comprising:

an input coupleable to receive a signal from the non-linear device;

a frequency monitor, coupled to the input, that monitors the level of even order distortion at a frequency and that creates a signal indicative of the level of the distortion without the use of a pilot tone; and

a controller, coupled to the frequency monitor to receive the first signal and to selectively create at least one control signal to control the non-linear device.

15. The control circuit of claim 14, wherein the non-linear device comprises an optical transmitter.

16. The control circuit of claim 14, and further including a pre-distorter coupled to the non-linear device and controlled by the controller.

17. The control circuit of claim 16, wherein the controller generates first and second control signals, wherein the first control signal controls a bias voltage for the pre-distorter and the second control signal controls a DC bias for the non-linear device.

18. The control circuit of claim 14, wherein the frequency monitor includes at least one filter and a mixer that select the frequency and down converts the frequency to base-band.

19. The control circuit of claim 14, wherein the frequency monitor monitors distortion products at a frequency outside the channel raster alignment, wherein the frequency is representative of even order distortion.

20. A control circuit for dynamic distortion control in a non-linear device, the control circuit comprising:

an input coupleable to receive a signal from the non-linear device;

a first frequency monitor, coupled to the input, that monitors the level of one of even and odd order distortion at a first frequency and that creates a first signal indicative of the level of the distortion without the use of a pilot tone;

a second frequency monitor, coupled to the input, that monitors the level of the other of even and odd order distortion at a second frequency and that creates a second signal indicative of the level of the distortion; and

a controller, coupled to the first frequency monitor and second frequency monitors, that receives the first and second signals and that selectively creates at least one control signal to control the non-linear device.

21. The control circuit of claim 20, wherein the non-linear device comprises an optical transmitter.

22. The control circuit of claim 20, and further including a pre-distorter coupled to the non-linear device and controlled by the controller.

23. The control circuit of claim 22, wherein the controller generates first and second control signals, wherein the first control signal controls a bias voltage for the pre-distorter and the second control signal controls a DC bias for the non-linear device.

24. The control circuit of claim 20, wherein the first frequency monitor includes at least one filter and a mixer that select the first frequency and down converts the frequency to base-band.

25. The control circuit of claim 20, wherein:

the first frequency monitor monitors first distortion products at a frequency outside the channel raster alignment, wherein the frequency is representative of one of odd or even order distortion; and

the second frequency monitor monitors second distortion products at a frequency outside the channel raster alignment, wherein the frequency is representative of one of odd or even order distortion.

26. The control circuit of claim 20, wherein the first and second frequency monitors include double balanced mixers.

27. The control circuit of claim 20, and further including a pilot tone generator that selectively adds distortion detectable at the second frequency.

28. An apparatus, comprising:

an input, coupleable to receive an RF signal;

a pre-distorter, coupled to the input, that selectively adds distortion to the RF signal;

a non-linear device, coupled to the pre-distorter, that receives the RF signal from the pre-distorter to produce an output for apparatus;

wherein the distortion added by the pre-distorter is controlled to reduce distortions in the output of the apparatus generated by the non-linear device;

a distortion monitor, coupled to the output of the non-linear device, that monitors at least one frequency of the output of a transmitter to detect distortion in the output without the use of a pilot tone; and

a microprocessor, coupled to the distortion monitor, the pre-distorter, and the non-linear device that uses an output of the distortion monitor to selectively generate at least one control signal for one of the non-linear device and the pre-distorter to reduce the distortion in the output of a transmitter.

29. An apparatus, comprising:

a non-linear device that receives an input signal and produces an output signal; and

a distortion monitor, coupled to the output of the non-linear device, that monitors at least one frequency of the output signal of the non-linear device to detect distortion without the use of a pilot tone.

30. The apparatus of claim 29, and further including a microprocessor, coupled to the distortion monitor, that provides at least one control signal to the non-linear device.

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[54] **SIGNAL LEVEL CONTROL CIRCUITRY FOR A FIBER COMMUNICATIONS SYSTEM**

[75] Inventors: **Frank R. Little**, Alpharetta; **John G. Megna**, Lilburn; **Heather H. Rand**, Alpharetta; **Frederick T. Zendt**, Norcross, all of Ga.

[73] Assignee: **Scientific-Atlanta, Inc.**, Norcross, Ga.

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[52] **U.S. Cl.** .... **359/154**; 359/161; 359/187; 359/194; 359/133; 330/59; 330/284; 250/214 A

[58] **Field of Search** .... 359/154, 157, 161, 173, 359/180, 187-189, 194-195, 132-133; 330/59, 308, 284; 250/214 A

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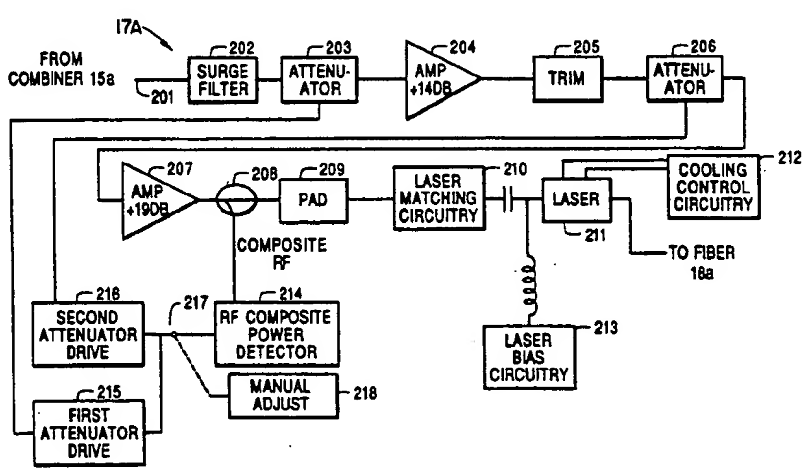
Primary Examiner—Richard E. Chilcot, Jr.
Assistant Examiner—Kinfe-Michael Negash
Attorney, Agent, or Firm—William A. Marvin; Frederick W. Powers, III

[57] **ABSTRACT**

A system for signal level control in AM fiber systems is provided. The system provides level controls at both transmitter and receiver ends of the fiber transmission system, utilizing compensation and control techniques at each end to maintain and optimize the performance of the system. The transmitter includes two stage level control based on a composite power level of a detected RF signal. The receiver includes two stage level control based on a pilot channel filtered from the channels transmitted to the receiver.

28 Claims, 9 Drawing Sheets



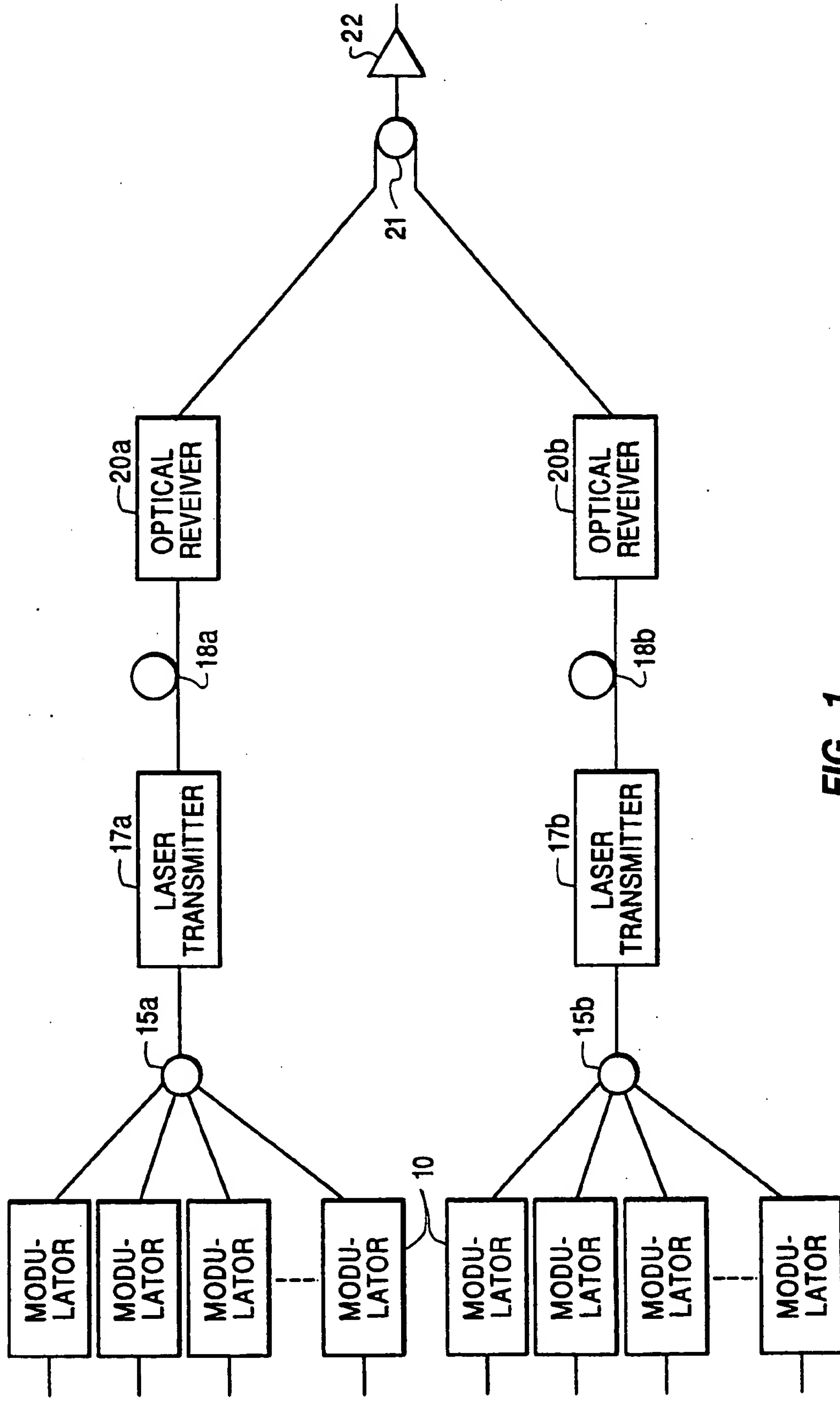

22
21
OPTICAL REVEIVER
20a
OPTICAL REVEIVER
20b
18a
18b
LASER TRANSMITTER
17a
LASER TRANSMITTER
17b
15a
15b
10
MODU-LATOR
MODU-LATOR
MODU-LATOR
MODU-LATOR
MODU-LATOR
MODU-LATOR
MODU-LATOR
MODU-LATOR

FIG. 1

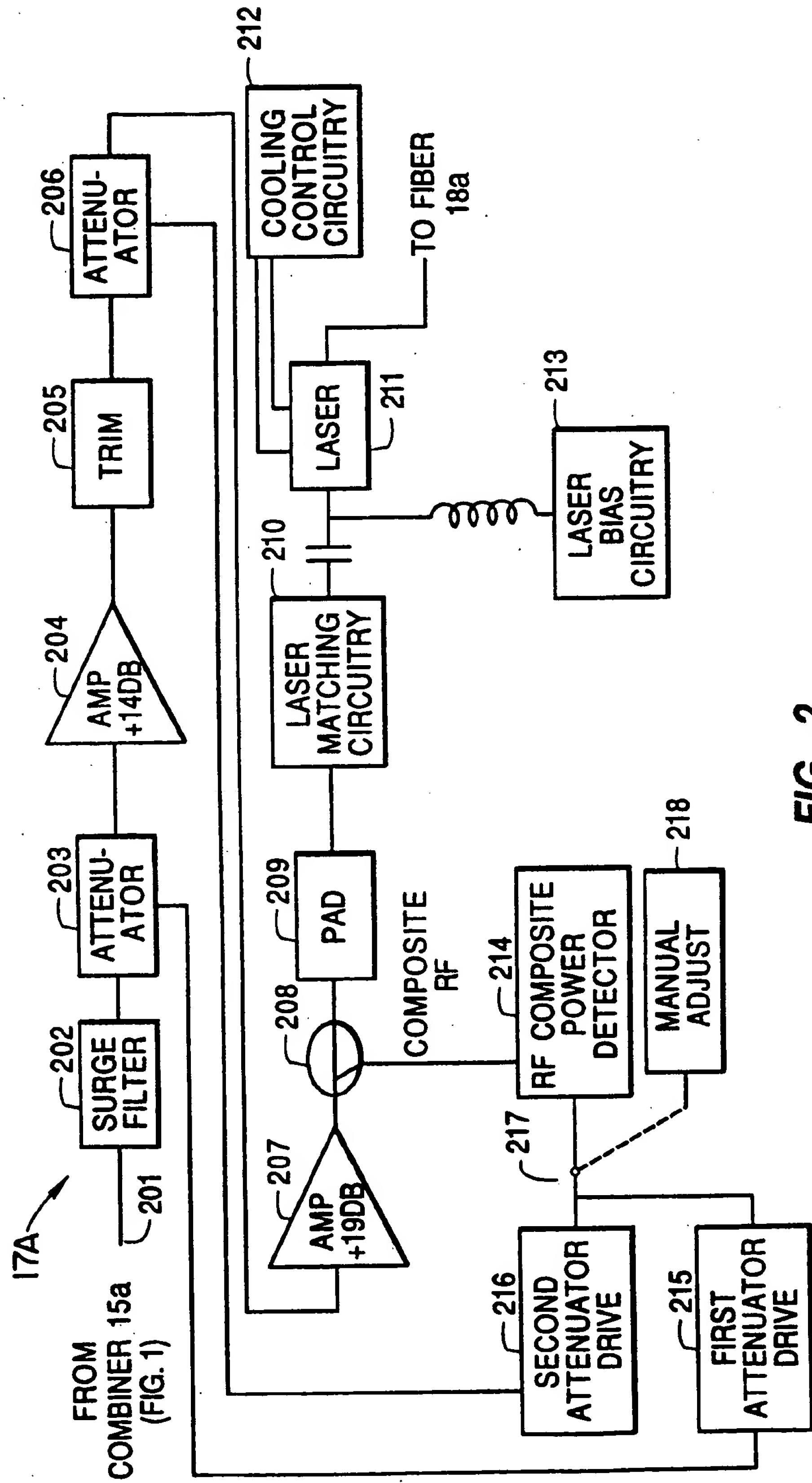

17A
FROM COMBINER 15a (FIG. 1)
201
202
SURGE FILTER
203
ATTENU-ATOR
204
AMP +14DB
205
TRIM
206
ATTENU-ATOR
207
AMP +19DB
208
COMPOSITE RF
209
PAD
210
LASER MATCHING CIRCUITRY
211
LASER
212
COOLING CONTROL CIRCUITRY
TO FIBER 18a
213
LASER BIAS CIRCUITRY
214
RF COMPOSITE POWER DETECTOR
215
FIRST ATTENUATOR DRIVE
216
SECOND ATTENUATOR DRIVE
217
218
MANUAL ADJUST

FIG. 2

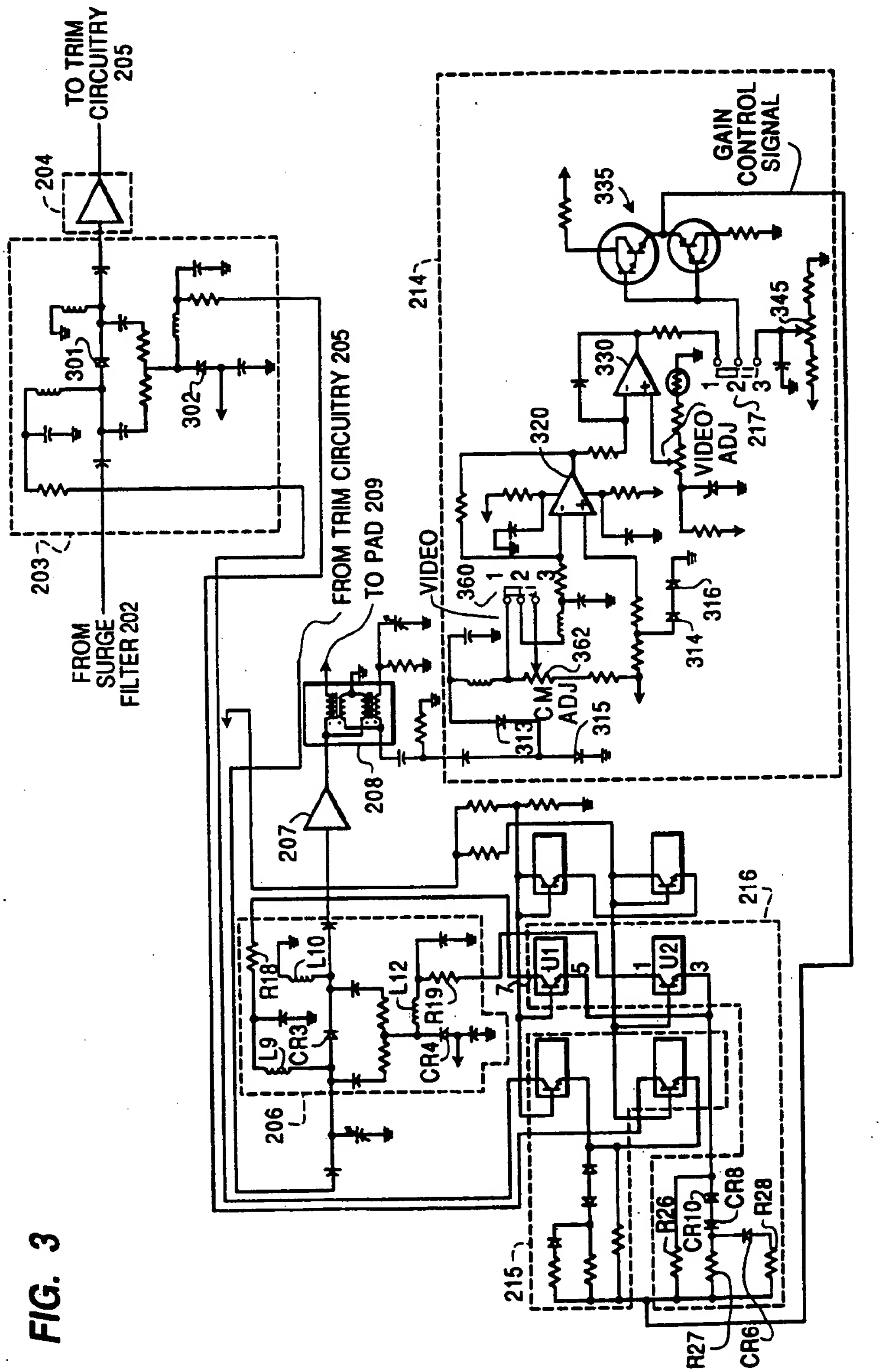

TO TRIM CIRCUITRY 205
204
203
FROM SURGE FILTER 202
301
302
FROM TRIM CIRCUITRY 205
TO PAD 209
VIDEO
360
208
207
214
335
GAIN CONTROL SIGNAL
330
320
345
VIDEO ADJ
217
316
314
362
CM ADJ
315
313
206
L9
CR3
R18
L10
L12
R19
CR4
U1
U2
216
215
R26
CR10
CR8
R28
R27
CR6

FIG. 3

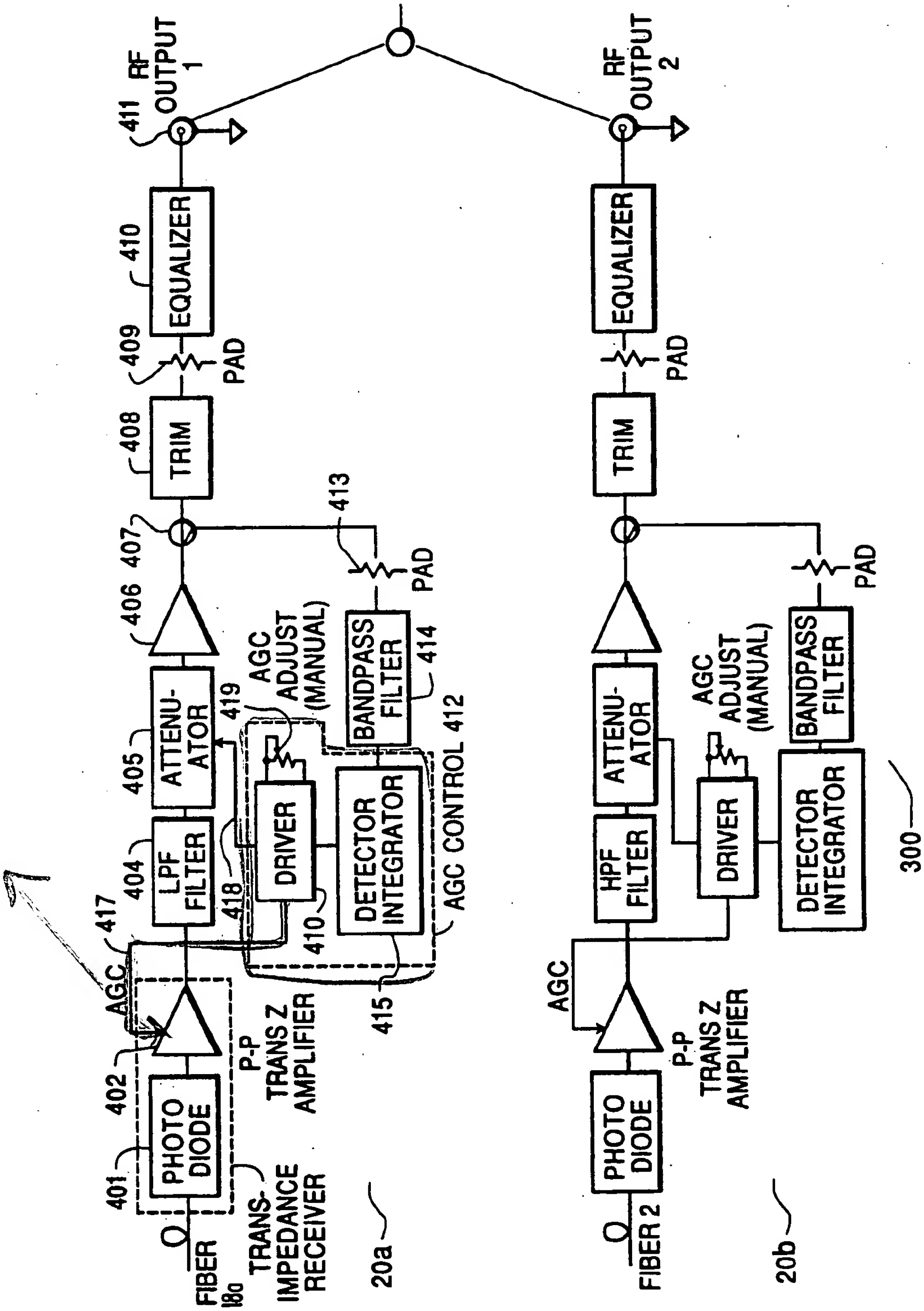

411
RF OUTPUT 1
410
EQUALIZER
409
PAD
408
TRIM
407
413
PAD
406
405
ATTENU-ATOR
419
AGC ADJUST (MANUAL)
BANDPASS FILTER
414
AGC CONTROL 412
404
LPF FILTER
418
DRIVER
410
DETECTOR INTEGRATOR
415
417
AGC
402
P-P TRANS Z AMPLIFIER
401
PHOTO DIODE
TRANS-IMPEDANCE RECEIVER
FIBER 18a
20a
RF OUTPUT 2
EQUALIZER
PAD
TRIM
PAD
ATTENU-ATOR
AGC ADJUST (MANUAL)
BANDPASS FILTER
HPF FILTER
DRIVER
DETECTOR INTEGRATOR
AGC
P-P TRANS Z AMPLIFIER
PHOTO DIODE
FIBER 2
20b
300

FIG. 4

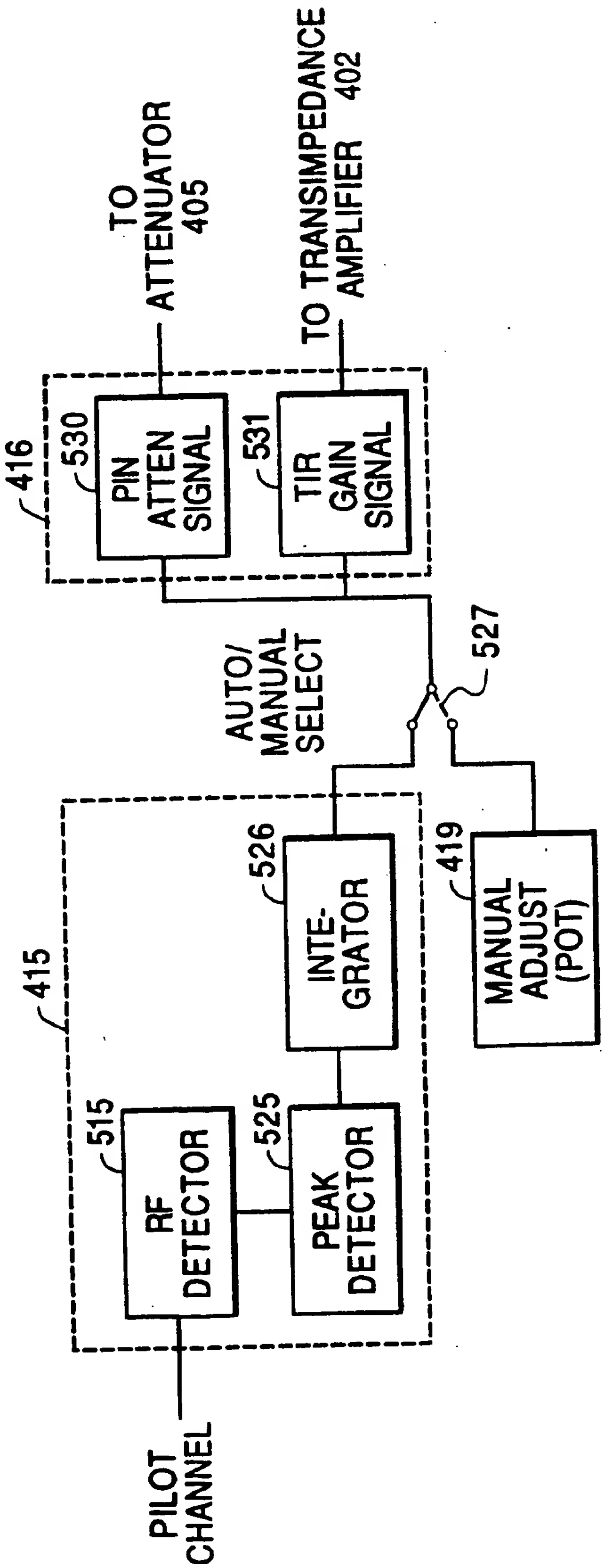

TO ATTENUATOR 405
TO TRANSIMPEDANCE AMPLIFIER 402
416
530
PIN ATTEN SIGNAL
531
TIR GAIN SIGNAL
AUTO/ MANUAL SELECT
527
415
526
INTE-GRATOR
419
MANUAL ADJUST (POT)
515
RF DETECTOR
525
PEAK DETECTOR
PILOT CHANNEL

FIG. 5

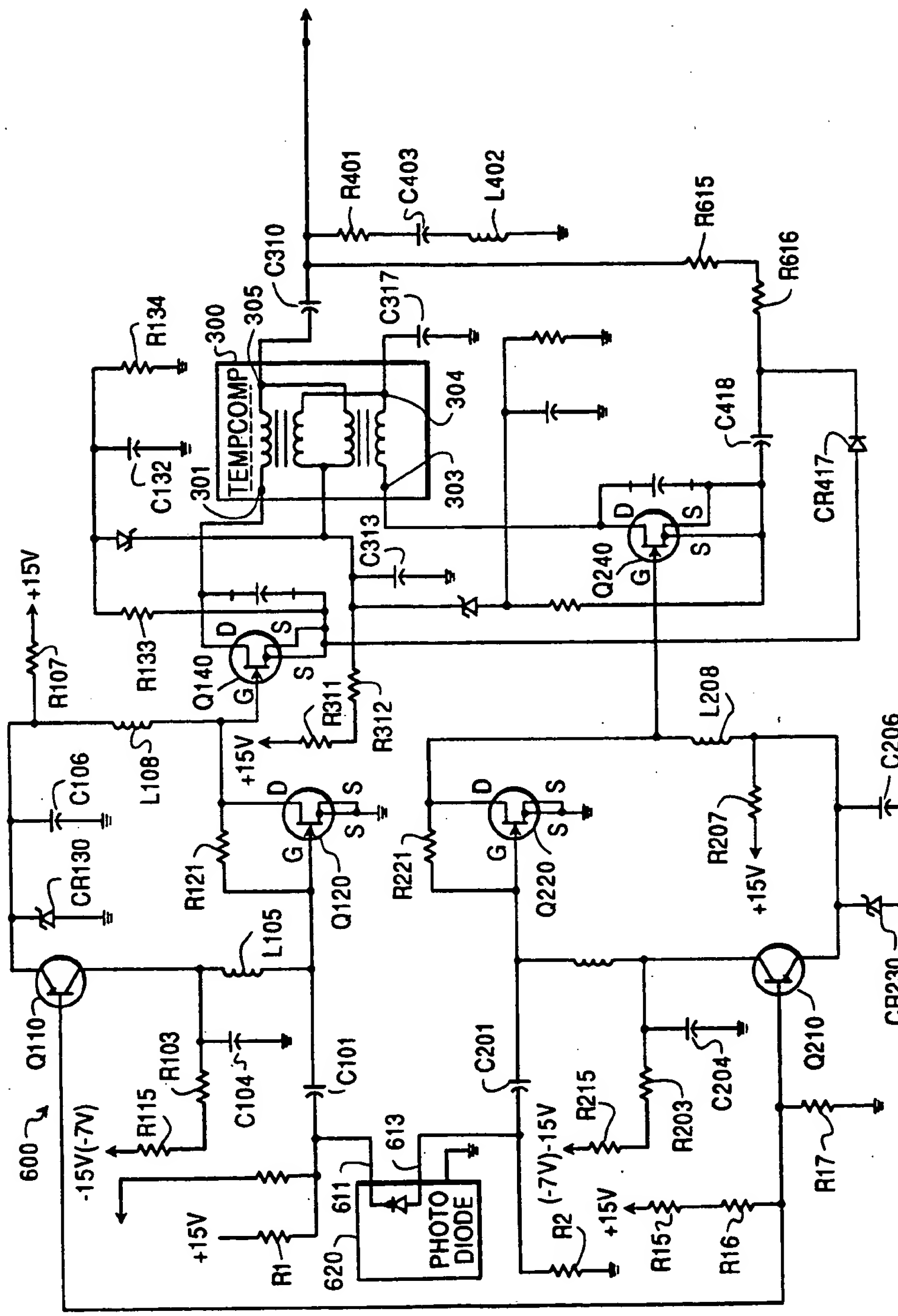

R401
C403
L402
C310
R615
R616
R134
300
305
C317
TEMPCOMP
304
303
301
C132
C418
CR417
C313
+15V
R107
R133
Q140
R311
R312
Q240
L208
C206
L108
C106
CR130
R121
Q120
+15V
R221
Q220
R207
+15V
CR230
L105
Q110
R103
C104
R115
-15V(-7V)
600
C101
C201
R215
(-7V)-15V
R203
C204
Q210
R17
601
613
611
PHOTO DIODE
620
+15V
R1
R2
+15V
R15
R16
D
S
G

FIG. 6

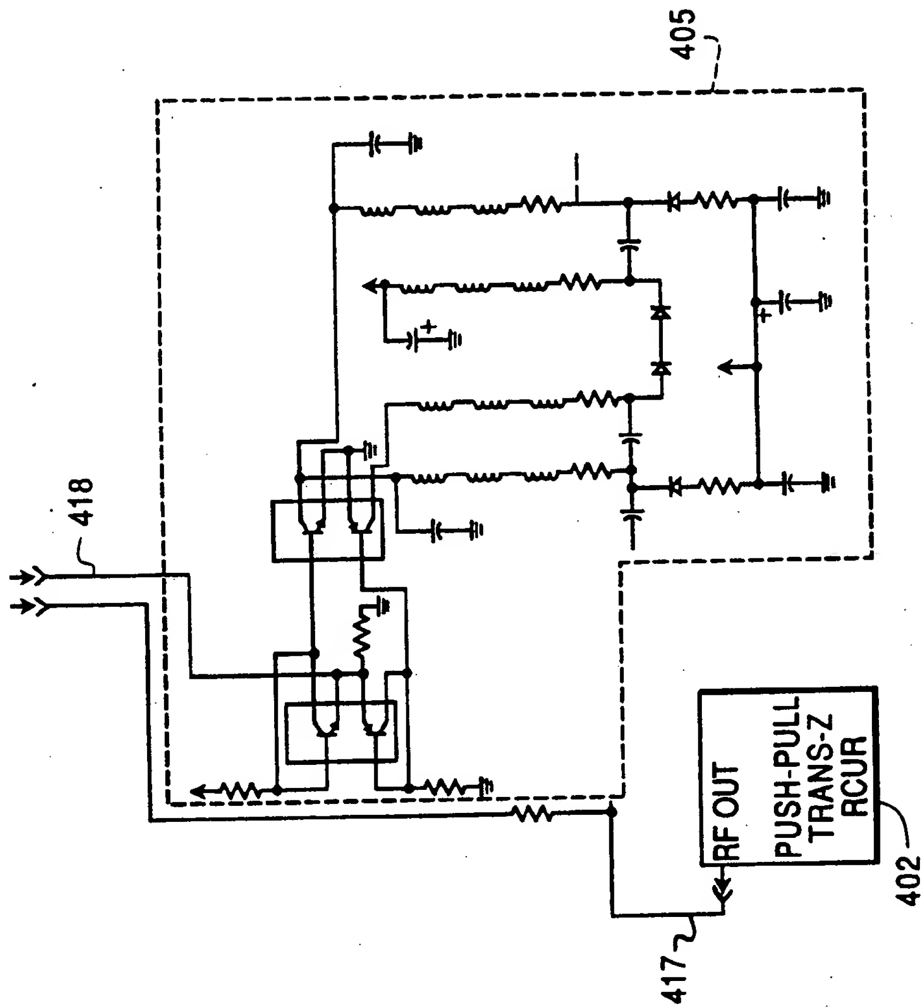


FIG. 7

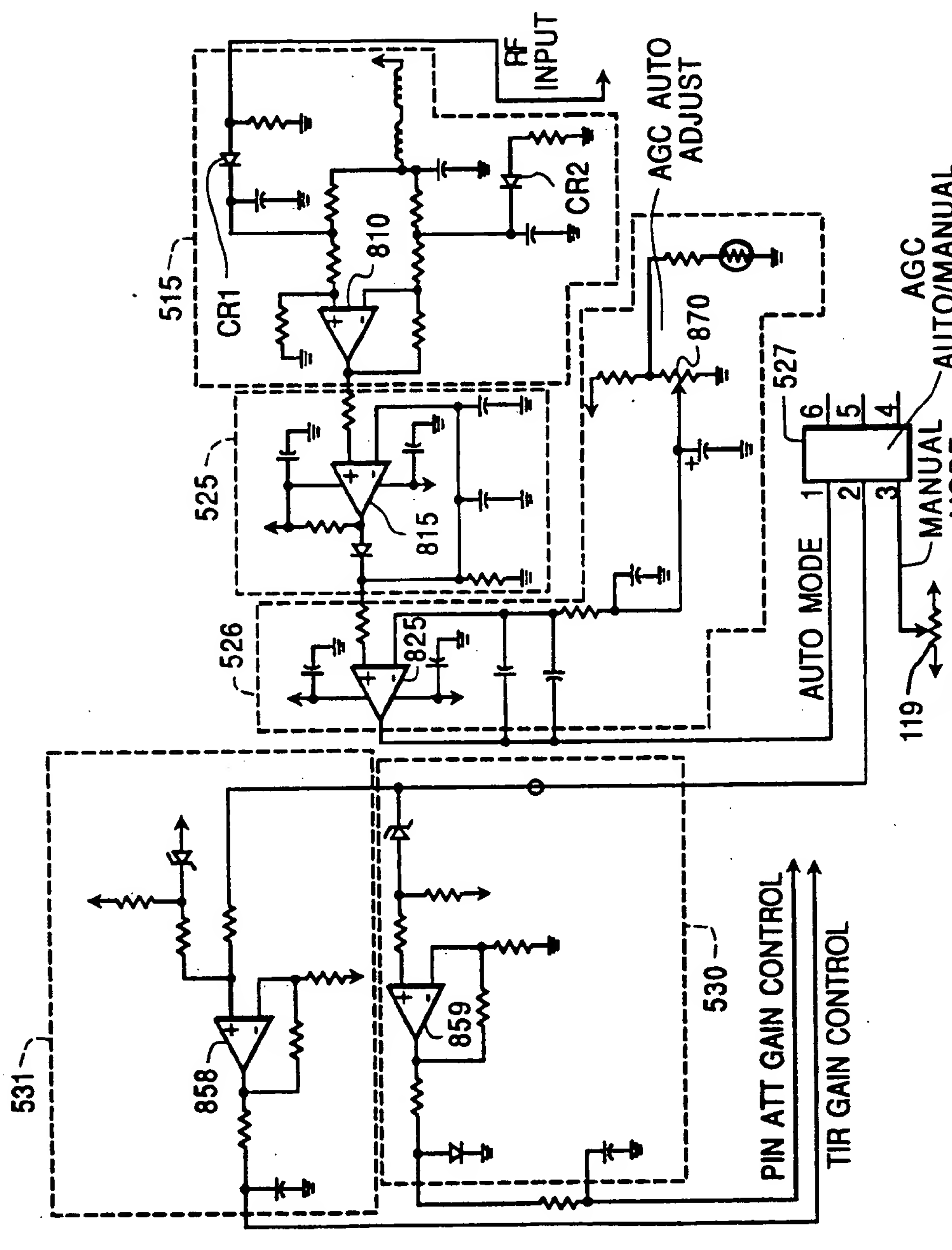

RF INPUT
AGC AUTO ADJUST
515
CR1
CR2
810
525
815
526
825
870
527
AGC AUTO/MANUAL SELECT
AUTO MODE
MANUAL MODE
MANUAL
1
2
3
4
5
6
119
AGC MANUAL ADJUST
531
858
859
530
PIN ATT GAIN CONTROL
TIR GAIN CONTROL

FIG. 8

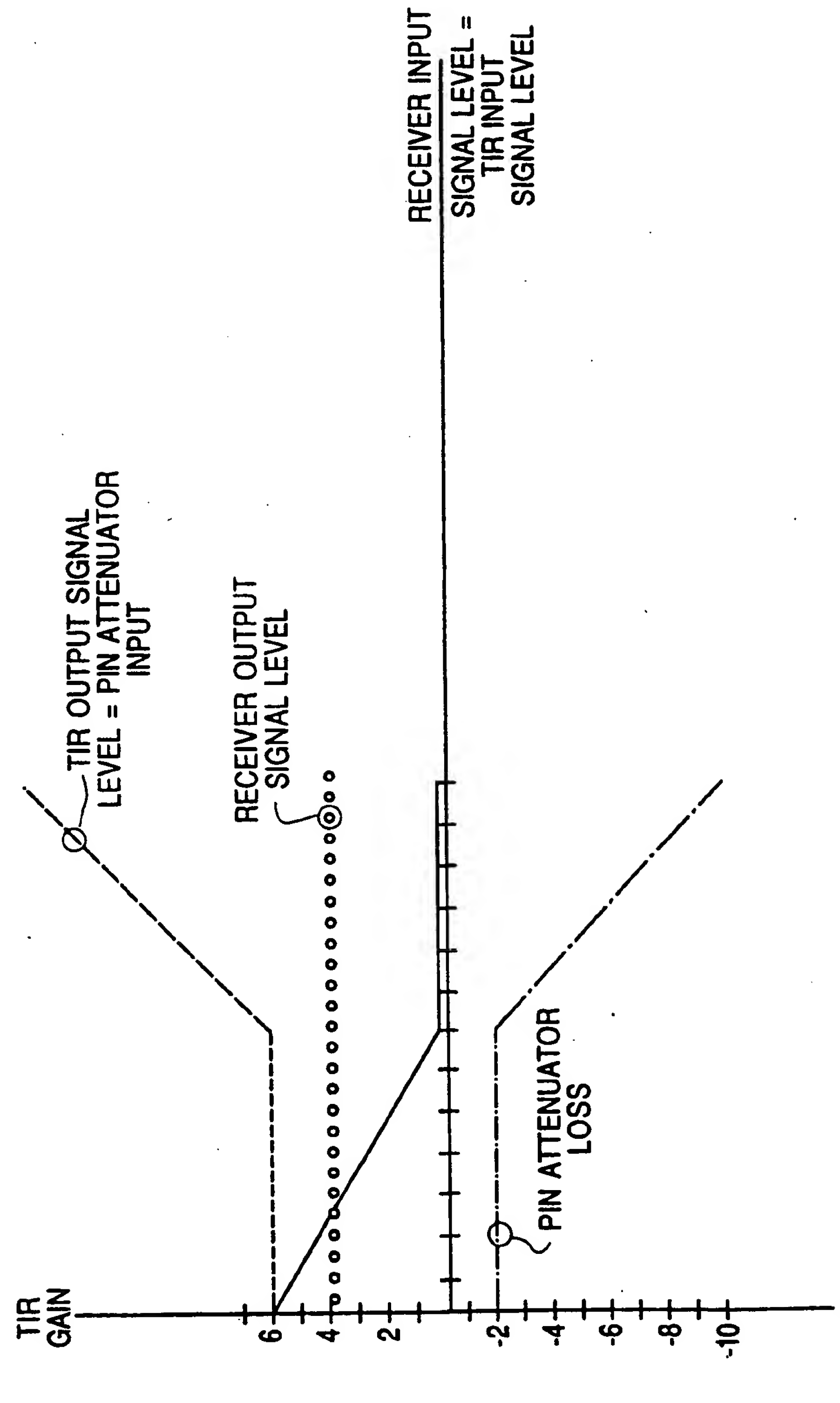

TIR OUTPUT SIGNAL LEVEL = PIN ATTENUATOR INPUT
RECEIVER OUTPUT SIGNAL LEVEL
RECEIVER INPUT SIGNAL LEVEL = TIR INPUT SIGNAL LEVEL
TIR GAIN
6
4
2
-2
-4
-6
-8
-10
PIN ATTENUATOR LOSS
PIN ATTENUATOR LOSS

FIG. 9

SIGNAL LEVEL CONTROL CIRCUITRY FOR A FIBER COMMUNICATIONS SYSTEM

FIELD OF THE INVENTION

The present invention relates to fiber communications systems and, more particularly, to methods and apparatus for signal level control in a fiber communications system such as a CATV system.

BACKGROUND OF THE INVENTION

In recent years, there has been a great deal of interest in the transmission of video signals via optical fibers. This mode of signal transmission offers a number of advantages over transmitting signals by conventional coaxial cable video signal distribution as is now commonly accomplished in CATV systems. Optical fibers intrinsically have more information-carrying capacity than do coaxial cables. In addition, there is less signal attenuation in optical fibers than in coaxial cable adapted for carrying radio frequency (RF) signals. Consequently, optical fibers can span longer distances between signal regenerators than is possible with coaxial cable. In addition, the dielectric nature of optical fiber eliminates any problems with electrical shorting. Finally, optical fiber is immune to ambient electromagnetic interference (EMI) and generates no EMI of its own.

Amplitude modulation, or more specifically, intensity modulation, of an optical signal by a wideband radio frequency signal requires a light modulating device, such as a laser, which has linear characteristics over a wide dynamic range of operation. Until recently it has been difficult to fabricate lasers in which the relationship between input current and optical output was linear over more than an extremely limited range. Because of this difficulty in obtaining lasers which were sufficiently linear to support analog intensity modulation, digital intensity modulation was, until recently, the primary means for transmitting information by optical signals. However, recent advances in laser technology have made analog intensity modulation of optical signals feasible. Currently available Fabry-Perot (FP) and Distributed Feedback (DFB) lasers have sufficiently linear characteristics to allow them to be used as analog modulators of optical signals.

An important advantage of AM fiber systems for CATV is that the same multichannel NTSC, PAL, or SECAM signal format is maintained throughout the system. No format conversion electronics are required at either end of the optical link. This makes the AM fiber optic system "friendly" to the CATV system tie-in points. Because of this advantage, AM fiber optic systems generally require less equipment space in the installation. An AM system is also less costly to install, particularly on a per channel basis, than either FM or digital systems.

The single mode optical fiber used in AM fiber systems possesses attenuation characteristics which change extremely little with temperature variations, unlike coaxial cable. In most current AM fiber architectures, little compensation for the optical fiber response is required. However, the carrier-to-noise ratio (CNR) and intermodulation distortion performance (composite triple beat, composite second order) of AM fiber systems is tied directly to the relative level of the multichannel carriers which modulate the laser. Because of this, the issue of signal level control is important throughout initial equipment set-up, ongoing operation, and system maintenance.

The signals modulating an AM laser have certain ideal requirements. The laser used in the transmitter exhibits optimum performance for a given application when operated at a specific composite modulation index. The RF drive level per channel modulating the laser is the determining factor in the composite modulation index of the laser. Ideally, the modulation index of the laser should be precisely maintained at its optimum value to ensure specified system carrier-to-noise ratio and intermodulation distortion performance. If the laser modulation index is too large, the CNR performance improves, but the distortion performance is compromised. On the other hand, if the laser modulation index is too small, the distortion performance improves, but the CNR performance is compromised.

In general, a larger composite modulation index is required to meet higher system CNR specifications. However, a maximum modulation index exists for each laser. Above this index, laser distortion performance begins to deteriorate rapidly due to signal clipping. In high CNR performance systems, the laser is generally operating at or near its maximum composite modulation index. Channel loading also has an effect on laser modulation index. As channel loading increases, the laser composite modulation index increases, and the intermodulation distortion performance degrades.

The laser transmitter is also affected by variations in the headend output RF level due to other factors. The addition or removal of a coupler, tap, or other equipment in the headend wiring scheme can cause changes in the resultant headend RF output level. The headend RF output level also varies slightly with time, temperature, regular maintanance, and adjustments.

These variations in the signals modulating the laser degrade the quality of the transmitted signal, reducing the ability to delivery high quality signals such as video signals in fiber optic communications systems.

At the receiver, the quality of the received optical signal is affected by the fiber plant and the optical transmitter. The number and quality of connectors and splices used in field installation may differ from the originally specified plan, resulting in a different optical loss. If an OTDR measurement used to determine optical is inaccurate, then again the optical power will differ from that expected. The average intensity of the received optical signal may change due to maintanance or repair of the fiber plant. Re-routing an optical path will also affect the optical link loss. As discussed above, several aspects of the transmitter design and RF signal source can also affect the optical signal. The composite modulation index may change as a result of the addition or deletion of channels, variations of signal level, or other changes to the laser drive signal. Additionally, the laser diode output power may vary due to aging or temperature variation.

Receiver performance as measured by carrier-to-noise ratio (CNR) and distortions, composite triple beat (CTB) and composite second order (CSO) is generally degraded by non-ideal optical signals. As the optical input power or modulation index increases, the CNR performance of the receiver generally increases, but the contribution of the receiver to the system distortion increases. Conversely, as the optical input power or modulation index decreases, the contribution of the

receiver to system distortion decreases, but the CNR performance of the receiver also decreases.

If variations in optical loss occur, the optoelectronic receiver performance may be affected. If the optical loss is greater than expected, the received optical power is lower than expected. Lower than expected received optical power results in a reduced RF output from the photodetector and optoelectronic receiver. Consequently, the input level to the receiver post-amplifier is lower. This condition increases the significance of the noise contribution of the receiver post-amplifier to the system CNR. The final result may be a degradation in system CNR. If the optical loss is less than expected, the received optical power is higher than expected. This results in an increased RF output level from the photodetector and optoelectronic receiver and generally improves the system CNR. However, with the optoelectronic receiver operating at a higher output level, its contribution to the system distortion is greater. The post-amplifier is also operating at a higher level and may contribute further to the system distortion. Consequently, there may be a degradation in system distortion performance.

Again, these factors limit the ability to deliver high quality signals such as video signal in a fiber optic communications systems.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide methods and apparatus for delivering high quality signals in a fiber optic communication system.

It is another object of the present invention to provide an improved transmitter for a fiber optics communications system.

It is another object of the present invention to provide an improved receiver for a fiber optics communications system.

The present invention achieves these and other objects by providing a system approach to signal level control in AM fiber systems. This set of level controls operates at both transmitter and receiver ends of the fiber transmission system, utilizing different compensation and control techniques at each end to maintain and optimize the performance of the system. Since optical fiber loss characteristics do not change as much as the loss characteristics of coaxial cable, taps, and passives with variations in temperature, the level control system of the present invention compensates for other parameters such as system input and output level variations due to changes in optical loss, system input signal levels, and physical placement of components within the system architecture.

To achieve these objects, the present invention employs, inter alia, a composite RF envelope power detector as the sensing element at the transmitter and a single channel RF carrier peak detector as the sensing element at the receiver. This permits control of the overall input RF modulation envelope used to modulate a linear laser source in the transmitter, and maintains a constant RF lever per carrier in the detected RF modulation envelope at the output of the receiver.

The present invention utilizes gain control circuitry to compensate for variations in signal level. At the transmitter, the composite RF power modulating the laser is monitored and the level of the entire spectrum of channels is adjusted by the same amount to maintain a constant composite power. A composite power AGC for an AM laser transmitter maintains a constant laser modulation index with headend RF level variations and changes in channel loading. Therefore, optimum transmitter distortion performance is preserved. In addition, the composite power AGC can be used to guard against an RF overdrive condition. If the level from one modulator increases by a large amount, the composite power AGC detects the input composite and adjusts the RF level modulating the laser.

Also in accordance with the present invention, gain control circuitry is incorporated into the receiver to compensate for variations in optical loss, modulation index, and channel loading. At the receiver, a single pilot channel is monitored to maintain a constant RF channel level at the output of the optoelectronic receiver. Gain control circuitry controls the gain at the receiver on the basis of changes in the signal level of the pilot channel. This technique maintains a constant RF channel output level and a constant contribution to system CNR by the receiver amplifier and post-amplifier. The RF channel output level of the receiver remains constant with variations in received optical power, modulation index, and channel loading.

In addition to providing an improved transmitter and receiver, the present invention also relates to system wide level control. A pilot channel type AGC can result in distortion changes of the receiver amplifier with variations in channel loading. Thus, if the channel loading increases, distortion due to the receiver amplifier increases and system distortion may increase. However, in accordance with one feature of the present invention when a transmitter with composite power AGC is utilized in combination with a receiver having a pilot channel type AGC, distortion remains unchanged. This combination results in consistent system distortion, good system CNR, and constant system RF output level.

Additionally, in a multiple band system, the present invention maintains a consistent RF channel level between bands. This is important when the bands are combined to produce a single RF signal. Thus, increased channel loading in one band, for example, will not result in RF channel level differences between that band and another band having less channel loading.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the present invention as well as a presently preferred embodiment thereof will become more apparent from a reading of the following description in connection with the accompanying drawings.

FIG. 1 is a block diagram of a fiber communications system.

FIG. 2 is a block diagram of a transmitter in accordance with the present invention.

FIG. 3 is a schematic diagram of the gain control circuitry of the transmitter of FIG. 2.

FIG. 4 is a block diagram of a receiver in accordance with the present invention.

FIG. 5 is a block diagram of the AGC control for the receiver of FIG. 4.

FIG. 6 is a schematic diagram of a transimpedance receiver used in the present invention.

FIG. 7 is a schematic diagram of the attenuator of FIG. 4.

FIG. 8 is a schematic diagram of the AGC control shown in FIG. 5.

FIG. 9 is a graph illustrating a relationship of receiver input signal level versus transimpedance receiver gain and attenuator loss.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a fiber communications system. In a currently preferred embodiment, the system is a CATV AM fiber system, although the invention is not limited in this respect. Individual frequency channels from multiple headend modulators **10** feed combining networks **15***a* and **15***b*. Combining networks **15***a* and **15***b* gather the channels into bands of frequencies to be transported by the distribution plant. These bands of channels provide a modulation input to laser transmitters **17***a* and **17***b*. For example, transmitter **17***a* may receive an RF input in a frequency band from 50–276 MHz and transmitter **17***b* may receive an RF input in a frequency band from 276–450 or 550 MHz AM laser transmitters **17***a* and **17***b* condition the composite headend signals to provide a signal which modulates the bias current of a semiconductor laser. This results in an intensity (power) modulated optical signal out of the laser. The optical signal is carried by low loss, single mode optical fibers **18***a* and **18***b* to optical receivers **20***a* and **20***b*. Optical receivers **20***a* and **20***b* include a photodetector which converts the optical signals into electrical signal currents. The electrical signals are replicas of the headend composite channel bands. The signals are combined by combiner **21**, amplified by amplifier **22**, and fed to a distribution plant.

FIG. 2 is a block diagram of transmitter **17***a* in accordance with a preferred embodiment of the present invention. An RF signal from combiner **15***a* is input to transmitter **17***a* at **201**. The signal passes to surge filter **202**. Surge filter **202** is a high pass filter designed to filter out lower frequency signals and noise, for example, below forty megahertz (40 Mhz). Such signals and noise may be due, for example, the lightning or other electrical interference. The signal then passes to first attenuator **203**. Attenuator **203** is preferably a pin attenuator designed to provide up to approximately 5 dB of attenuation, although the invention is not limited in this respect.

The output of attenuator **203** is supplied to first hybrid amplifier **204** which provides an amplification of, for example, 14 dB. The output of hybrid amplifier **204** is supplied to frequency response trim circuitry **205** which trims or smoothes out the frequency response of the signal. The output of trim circuitry **205** is supplied to second attenuator **206**. Attenuator **206** is preferably a pin attenuator configured in the same manner as attenuator **203**, although this is not required. Attenuator **206** provides up to approximately 5 dB of attenuation, although the invention is not limited in this respect. The output of attenuator **206** is supplied to second hybrid amplifier **207** which provides, for example, an amplification of 19 dB. Hybrid amplifier **207** preferably has better distortion characteristics than hybrid amplifier **204** since the signal level at this point in the transmitter is significantly higher.

The output of hybrid amplifier **207** is supplied to directional coupler **208**. The coupled signal of directional coupler **208** is supplied to RF composite power detector **214**. The detected composite RF signal is used to generate a gain control signal which is supplied to first attenuator drive circuit **215** and second attenuator drive circuit **216**. The output signals of these drive circuits respectively control first attenuator **203** and second attenuator **206**. In accordance with the detected composite RF level, the attenuation of attenuators **203** and **206** is varied as needed to maintain the through signal of directional coupler **208** at a constant level. When switch **217** contacts manual adjust **218**, first and second attenuator drives **215** and **216** may be manually controlled, for example, by setting a potentiometer.

The through signal of directional coupler **208** is provided to pad **209** for adjusting the signal level into laser **211**. The gain control circuitry ensures that the signal level into pad **209** is constant and pad **209** adjusts this level. The signal from pad **209** is provided to laser matching circuitry **210**. Matching circuitry **210** matches the 75 ohm coaxial system to lower the laser impedance. The output of laser matching circuitry **210** modulates laser **211**. Laser **211** is a high-performance analog laser, preferably of the distributed feedback (DFB) type, with an integral optical isolator, thermoelectric cooler monitor photodiode, and thermistor. To maintain a proper output power level, the temperature of the laser is controlled by cooling circuitry **212**. Laser bias circuitry **213** is used to adjust the laser bias current.

FIG. 3 is a schematic diagram of the gain control circuitry of the transmitter of FIG. 2. Attenuator **203** is a pin attenuator. The pin attenuator is a bridged T-network. As the currents in pin diodes **301** and **302** are varied, the attenuation of the pin attenuator changes. The pin attenuator is designed to provide approximately 5 dB of attenuation. The currents through pin diodes **301** and **302** vary in opposite directions in order to maintain a seventy-five (75) ohm impedance. Although a bridged T-network is shown in FIG. 3, other arrangements may be utilized. Attenuator **206** is preferably a pin attenuator configured in the same manner as attenuator **203**.

The coupled signal of directional coupler **208** is provided to RF detector diodes **313** and **315**. Two diodes are utilized to reduce CSO caused by the diodes themselves. The detected composite RF singal is supplied to comparator **320** where it is compared with a temperature compensated DC reference to determine whether the composite RF level has gone up or down. Diodes **314** and **316** are matched with diodes **313** and **315** to provide temperature compensation. The output of comparator **320** is provided to integrator **330**. The integrated output of integrator **330** is amplified at amplification stage **335** to provide a gain control signal for determining the current to be driven through the pin diodes of attenuators **203** and **206**.

The AGC driver circuits include respective current mirrors responsive to the gain control signal for driving current through the pin diodes. In pin attenuator **206**, current flow is from +24 Volts, through CR4, L12, R19, U2(1), U2(3), U1(5), U1(7), R18, L9, CR3, L10, to ground. The gain control signal changes the magnitude of this current in accordance with changes in the detected signal level.

Linearization networks prior to the current mirrors ensure a linear attenuation in dB versus the voltage of the gain control signal. That is, as the voltage of the gain control signal changes in a certain step, the attenuation changes in a corresponding scaled step. A linearization network is provided for each of the pin attenuators. The linearization network for pin attenuator **206** includes resistors R26, R27, and R28 and diodes CR6, CR8, and CR10.

Switch 217 permits either automatic gain control or manual control to be implemented. If switch 217 contacts poles 2 and 3, gain control is implemented automatically as described above. If the switch contacts poles 1 and 2, the manual adjustment of potentiometer 345 determines the gain control signal.

Switch 360 takes into account the higher power of continuous wave (CW) signals used for system testing as compared to video signals used in actual field implementation. By switching switch 360 to the CW position, the setting of potentiometer 362 effectively reduces the power of the composite CW signal applied to comparator 320. Were the AGC set at the factory in accordance with the composite CW power, the normal video signals in actual field use would be regarded by the AGC circuitry as a loss in power, thereby causing a reduction in attenuation. This reduction effectively limits the attenuation range. Setting switch 360 to the CW position during testing allows for the full range of attenuation during actual use with video signals.

The present invention utilizes two stages of attenuation. This allows for increased attenuation range. Additionally, it is desirable not to have large attenuation before the first gain stage since this may adversely affect carrier-to-noise ratio. However, if some attenuation is introduced before and after the first gain stage, the carrier-to-noise remains acceptable. Additionally, operating the first gain stage at a lower signal level reduces the distortion caused by this stage. Since the laser is the primary cause of distortion in the transmitter, it is very desirable to limit the introduction of distortion at earlier stages.

As noted, the transmitter implements composite power gain control. Thus, the composite RF power modulating the laser is monitored and the level of the entire spectrum of channels is adjusted by the same amount to maintain a constant composite power. The advantage of composite power AGC for an AM laser transmitter is that it maintains a constant laser modulation index with headend RF level variations and changes in channel loading. Therefore optimum transmitter distortion performance is preserved. In addition, the composite power AGC can be used to guard against an RF overdrive condition. If the level from one modulator increases by a large amount, the composite power AGC detects the increase in transmitter input composite power and adjusts the RF level modulating the laser.

FIG. 4 is a block diagram of the receiver modules 20a and 20b of FIG. 1. As noted above, one receiver may receive a low band of channels and the other may receive a higher band of channels. Except as noted, the two receivers are identical and although receiver 20a is discussed in detail, the following description may be applied to both. An optical signal carried by fiber 18a is incident on photodiode 401. The optical signal is transformed by photodiode 401 into an electric current by the photoelectric effect. The electric current is then supplied to a push-pull transimpedance amplifier 402 which converts it to an amplified RF signal. The RF signal at the output of the push-pull transimpedance amplifier 402 consists of a broadband spectrum of video signals. Transimpedance amplifier 402 includes a gain circuit that maintains a specified RF output level as determined by an automatic gain control (AGC) circuit. Photodiode 401 and transimpedance amplifier 402 together constitute a transimpedance receiver. The transimpedance receiver and automatic gain control will be discussed in greater detail below.

The output of transimpedance amplifier 402 then passes to an input of low pass filter 404. Filter 404 is used in multiple band systems in order to maintain high system performance. The filter type and cutoff frequency are determined by system requirements. Conversely, the filter in the high band receiver 20b is a high pass filter. Filter 404 may be included or a jumper may be provided in single band systems.

The signal at the output of filter 404 is supplied to attenuator 405. Attenuator 405 is a variable attenuation block such as a pin attenuator. The attenuation of attenuator 405 is controlled by the AGC circuit as will be discussed in greater detail below. Assuming an insertion loss of about 2 to 3 dB, attenuator 405 provides from minimum attenuation up to approximately 6 to 10 dB of additional attenuation.

After the signal passes through attenuator 405, it is supplied to hybrid amplifier 406. Hybrid amplifier 406 provides the grain needed to obtain a desired module output level. The output of hybrid amplifier 406 is supplied to directional coupler 407. The through signal of directional coupler 407 is passed to trim network 408. Trim network 408 is an RF network to level out the response of the module. Variations in response may be caused by transimpedance amplifier 402, attenuator 405, and stray capacitances. Trim network 408, for example, "peaks up" carriers that are rolled off at the edge of the passband of filter 404. Trim network 408 may not be needed in single band systems since, as noted above, filters need not be used in such systems. The output of trim network 408 passes to pad 409. Pad 409 provides the ability to manually adjust the RF output level from the receiver module. Pad 409 enables the output of the high channel and low channel receiver to be matched. The signal from pad 409 passes to equalizer 410. Equalizer 410 compensates for a tilt or flat slope of the RF signal and/or provides a desired tilt at the output 411 of the receiver module.

The coupled RF signal of directional coupler 407 is monitored by the AGC circuitry 412. AGC circuitry 412 includes detector and integrator 415, and driver circuitry 416.

The portion of the RF signal that is monitored by the AGC circuitry 412 first passes to pad 413. Pad 413 permits adjustment of the level of the RF signal supplied to detector and integrator 415. The RF signal is passed through band pass filter 414. Bandpass filter 414 is a single channel, helical filter approximately six (6) to ten (10) Megahertz wide. Bandpass filter 414 passes only one channel of the RF signal and the passband center frequency of filter 414 is selected so a desired pilot channel is passed. The RF level of all channels are thus adjusted up or down based on the level of the pilot channel. The pilot channel RF signal is applied to the input of detector 415. Detector 415 converts the pilot channel RF signal to a DC voltage and compares the DC voltage to a reference voltage. This comparison determines the relative RF level in the module. A DC signal proportional to the RF level in the module is fed to AGC driver circuit 416.

AGC driver circuit 416 outputs signal 417 to adjust the gain in push-pull transimpedance amplifier 402 and signal 418 to adjust the attenuation of attenuator 405 as necessary to obtain a desired module RF output level. Thus, the level control of the present receiver is implemented in two stages, although the invention is not limited in this respect. The first stage is the gain control stage in the push-pull transimpedance receiver. The

purpose of this stage is to maintain a specified minimum output level from the transimpedance receiver. It is desirable to maintain a specified minimum output level from the transimpedance receiver in order to obtain a high system carrier-to-noise ratio. The first stage provides about a 6 dB range of gain control. The second gain control stage in the AGC system is attenuator **405**. This second stage maintains a constant output level and provides additional range for the AGC system. In a preferred embodiment, there is approximately 8 dB of attenuation control in attenuator **405**. A switch may be used to switch to manual mode. In manual mode, potentiometer **419** is set to control the gain.

A single carrier pilot type AGC maintains a constant RF channel level at the output of the receiver. The primary advantages of this technique are a constant RF output level and a constant contribution to system CNR by the receiver amplifier and post-amplifier. The RF channel output level of the receiver remains constant with variations in received optical power, modulation index and channel loading.

FIG. **5** is a block diagram of AGC control **412** for the receiver of FIG. **4**. The pilot channel from filter **414** (FIG. **4**) is supplied to RF detector **515**. RF detector **515** provides a signal that is proportional to the envelope of the detected RF signal. The signal passes to peak detector **525**. Peak detector **525** converts the envelope signal to a constant DC signal whose amplitude is proportional to the peak of the envelope signal. After peak detector **525**, the signal passes to integrator **526**. Integrator **526** effectively slows down the response time of the AGC circuit so that the signal level at the output of the receiver does not vary rapidly. The signal then goes through the auto/manual select switch **527**. When the switch is in the auto position, the output of integrator **526** provides a control signal for automatic gain control operation. When the switch is in the manual position, a DC voltage provided by a manually adjusted potentiometer **419** sets the gain. The DC signal from the auto/manual select switch is the gain control signal. The gain control signal is input to attenuator drive circuit **530** and transimpedance receiver gain drive circuit **531**.

FIG. **6** is a schematic diagram of a transimpedance receiver used with the present invention. Referring to the Figure, a photodetector, which is preferably a photodiode **620**, receives an optical input signal transmitted to it by optical fiber **18***a* (see FIG. **1**). Cathode terminal **611** of the photodiode **620** is connected through resistor R1 to a DC voltage which in the preferred embodiment is +15 Volts. Anode terminal **613** of the photodiode **620** is connected through a resistor R2 to ground. Terminal **611** of photodiode **620** feeds first transimpedance amplifier **600** through capacitor **C101**. Similarly, the other terminal **613** of photodiode **620** feeds second transimpedance amplifier **601** through blocking capacitor **C201**. Both of these transimpedance amplifiers **600** and **601** are configured identically, and the following description of the transimpedance amplifier **600** also applies to the transimpedance amplifier **601**. In this regard it will be noted that the tens and units digits of the identification number of each component in amplifier **600** are identical to the tens and units digits of the identification numbers in corresponding components of the amplifier **601**.

Transimpedance amplifier **600** is built around field effect transistor Q120, the source ("S") terminals of which are connected to ground. A feedback path is provided between the drain ("D") terminal of field effect transistor Q120 by feedback resistor **R121**.

The gate of field effect transistor Q120 is connected to the incoming RF signal passing through blocking capacitor **C101**. The DC voltage which is applied to the gate of field effect transistor Q120 is effectively controlled by a bias regulating circuit built around transistor Q110. The base of transistor Q110 is connected to ground through resistor **R17** and to the +15 volt power supply through resistors **R16** and **R15**. **R15, 16** and **17** are selected to provide an input bias reference voltage to the base of transistor Q110 of approximately +3 volts. The collector of transistor Q110 is connected to ground through blocking capacitor **C104** and to a −15 volt DC supply through resistors **R103** and **R115**. The collector of transistor Q110 is also connected to the gate of field effect transistor Q120 through inductor **L105**. The emitter of Q110 is connected to the +15 volt DC power through resistor **R107** and back to the drain of field effect transistor Q120 through an inductor **L108** which is essentially an open circuit to radio frequency signals. Paths to ground from the emitter of transistor Q110 are provided by blocking capacitor **C106** and a Zener diode **CR130** which is normally conductible and functions to limit the source to drain voltage of Q120 during turn ON/OFF during power interruptions. Transistor Q120 is a gallium arsenide field effect transistor (GASFET) with a maximum voltage rating of 5 volts.

In the above circuit, the base to emitter voltage drop across the transistor Q110 is approximately 0.7 volts. Thus, if the transistor is conducting, the voltage at the emitter of transistor Q110 will be approximately +3.7 volts.

In the above circuit, the inductor **L108** is constructed to behave as short circuit to DC signals and as a pure resistive component to AC signals at the radio frequencies in question (i.e., over 50 Mhz). Preferably, L108 will appear to be a resistive impedance of approximately 600 to 700 ohms at frequencies in the 50 Mhz to 550 Mhz range. The inductor **L108** may be formed of five turns of #30 enamel wire.

The drain terminal of field effect transistor Q120 is connected to terminal **301** at the primary winding of output transformer **300** via a high impedance buffer amplifier stage. This buffer amplifier stage includes a transistor **Q140** whose sources are connected to ground through resistor **R133** and resistor **R134**. A radio frequency path to ground is provided from a point in the circuit between resistor **R133** and **R134** by blocking capacitor **C132**. The drain of transistor **Q140** is connected to terminal **301** at the primary winding of the output transformer **300** and the gate of transistor Q140 is connected to the drain terminal of field effect transistor Q120.

The output transformer **300** is a ferrite core transformer which is similar to the type commonly used for broadband amplifier applications. The terminal **303** at the primary winding of the output transformer is connected to the output of the other transimpedance amplifier **501**. The center tap terminal **302** at the primary winding is connected to the +15 volt power supply through resistors **R312** and **R311** and to ground through blocking capacitor **C313**. The transformer **300** preferably has a 2 to 1 turns ratio or a 4 to 1 impedance ratio. The transformer **300** acts to transform the unbalanced load impedance at its output terminals **305** and **304** to a balanced load for the drains of transistors **Q140** and

Q240. The circuitry connected to the center tap terminal 302 of the primary winding of the transformer provides an AC short to ground at that point and also a path for the DC bias voltage to the drain of transistor Q140.

Blocking capacitor C317 provides a path from terminal 304 to ground for RF signals, and blocking capacitor C310 provides a path for the radio frequency signal to the output terminals of the receiver. The output of the receiver may, optionally, be connected to equalization network 400 comprising resistor 401 connected in series to comparator C403 which in turn is connected through resonating inductor L402 to ground. The equalization network 400 is utilized to correct for out any nonlinearities in the response of the receiver caused by imperfections in the remainder of the circuitry.

With feedback resistor R121 of transimpedance FET Q120 fixed, for a given optical signal incident on photodiode 520, a given RF level is provided by FET Q120. If the optical input level changes, the RF output level will change correspondingly. After the buffer amplifier, gain control is performed.

The transimpedance receiver of the present invention also includes automatic gain control circuitry. A DC control voltage is input on the RF output line. In the present receiver, the DC control voltage is the output of TIR gain drive 531 (FIG. 5). Capacitor C310 prevents the DC voltage from affecting the RF output transistors Q140 and Q240. The DC voltage serves to bias pin diode CR417 through resistors R615 and R616. Pin diode CR417 AC couples (due to the presence of capacitor C418) the sources of output FETs Q140 and Q240. When diode CR417 is OFF and offers a high impedance, it has no effect and the transimpedance receiver operates at maximum gain. As diode CR417 turns ON when the DC control voltage increases, diode CR417 appears as a lower impedance and the degeneration in the shunt leg of transistors Q140 and Q240 increases, i.e., the gain of transistors Q140 and Q240 is decreased. The output level may thus be varied by varying the gain of the output transistors Q140 and Q240 through varying the bias of diode CR417 in accordance with the output of TIR gain drive 531.

FIG. 7 is a schematic diagram of the attenuator 405 and its associated circuitry. The portions of the schematic diagram corresponding to blocks in the block diagram have been identified using the same reference numbers.

The attenuator control signal 418 from attenuator drive 530 determines the attenuation of attenuator 405 which, as shown in FIG. 7, is a pin attenuator. The resistance of a pin diode is a function of the current passing through it. By appropriately controlling that current, the attenuation can be controlled. That is, by controlling the attenuator control signal 418, the current through the respective pin diodes is varied in opposite directions and the attenuation is changed. This changes the RF level of the signal passing through by pin attenuator 405.

Similarly, control signal 417 controls the gain of the transimpedance receiver. As discussed above, the RF output line of the transimpedance receiver has a DC control signal superimposed thereon for controlling the gain of the amplifier thereof. The relationship of the transimpedance receiver control signal 417 and the pin attenuator control signal 418 will be explained below.

FIG. 8 is a schematic diagram of components shown in FIG. 5. With reference to FIG. 8, RF input is supplied as indicated. CR1 is a detector diode. CR2 is a matched diode. The output of the envelope detector has a DC bias on it. The second diode has the same DC bias on it. The first DC bias is subtracted from the second DC bias to compensate for drifts due to temperature, aging, etc. The RF envelope is provided at the output of op amp 810. Op amp 815 is part of peak detector 525. The RF envelope is a function of the RF modulation, i.e., the picture. A horizontal sync pulse is followed by picture information. Op amp 815 is used to determine the maximum level, i.e., the level of the horizontal sync pulse. The peak detector will slowly follow any drift in maximum signal level. The output of op amp 815 is supplied to op amp 825 of integrator 526. A fixed voltage is supplied to one input and the voltage on the other input is output of peak detector 525. The output of integrator 526 is the integral of the difference between these signals. This output is known as the error voltage and is measure of the difference between the two input signals.

This error signal is the signal which eventually adjusts all the AGC control lines. By varying the auto adjust potentiometer 870, the DC voltage supplied to the negative input of op amp 825 is made larger or smaller and thus, the error voltage is made larger or smaller. This generates a larger or smaller voltage signal controlling the transimpedance receiver and the attenuator. That is, given the peak detector output, by varying the potentiometer, the attenuators can be made to sit at different levels. This permits calibration of the RF output at a given time at some given level. For example, if the RF input is 17 dBmv, the gain of the transimpedance receiver may be at 6 dB and the attenuator of the attenuation at 0 dB.

The error voltage goes to the auto/manual switch 527. The switch selects whether gain control will be based on the error voltage or on the voltage as determined by the manual mode potentiometer 419.

In the present embodiment, the operating range for linear control of the diode circuits of the transimpedance amplifier and the pin attenuator is between −5 volts and +5 volts. That is, when the error voltage or the voltage determined by potentiometer 896 (hereinafter "control signal") is between −5 volts, the gain of the transimpedance receiver and the attenuator of the attenuation are controlled. Outside of this range, an indicator such as an alarm may be provided to an operator.

The output of op amp 858 is supplied to the TIR gain control and the output of op amp 859 goes to the pin attenuator control. These are the actual drive voltages for those attenuators. When the control signal to the inputs of these op amps is between about −5 volts and about 0 volts, the output of op amp 858 will vary and control the gain of the transimpedance receiver accordingly. The output of op amp 859 when the control signal is in the range between −5 and 0 remains constant at a voltage at which the pin attenuator has minimum attenuation. As the control signal varies from 0 to +5 volts, the output of op amp 859 changes to vary the attenuation of the attenuator from minimum to maximum attenuation. In this range, the output of op amp 858 remains constant and the gain of the transimpedance receiver remains at a minimum.

FIG. 9 graphically illustrates the implementation of gain control in accordance with the present invention. The Figure illustrates a graph of the receiver input signal level versus the transimpedance receiver gain and

pin attenuator loss. As shown by the solid line, as the receiver input signal level is initially increased from some initial value, the gain of the transimpedance receiver is decreased. This maintains a constant output signal level from the transimpedance receiver as shown by the dashed line and also maintains a constant output signal level from the receiver module. It can be seen with reference to the dot-dash line that during this initial increase, the pin attenuator loss remains constant at its minimum value.

When the gain of the transimpedance receiver has been controlled to its minimum value, further increases in the receiver input signal level will result in an increase in the signal level output of the transimpedance receiver as shown by the dashed line. However, at this point the pin attenuator begins to attenuate as shown by the dot-dash line. This acts to maintain a constant receiver output signal level as shown by the dotted line, even though the output of the transimpedance receiver is increasing. Accordingly, the receiver output signal level remains constant over a wide range of input signal levels.

A further feature of the present invention is a fiber system in which a composite power type AGC is implemented in a transmitter and a pilot channel type AGC is implemented in a receiver. The importance of headend signal level maintenance on the performance of a fiber system, including the AM fiber link, is critical and stability can be augmented by the use of a composite power sensing AGC in the transmitter. In a receiver, signal levels can best be stabilized versus optical loss variation, channel loading variations, and equipment changes by the use of a pilot carrier AGC. A pilot carrier type AGC can result in increased system distortion if channel loading increases. However, when using a transmitter with composite power AGC distortion remains unchanged. Thus, a system operator has great flexibility in adding channels without degrading system performance.

The use of pilot carrier AGC in the receiver offers additional benefits in multiple band systems such as that illustrated in FIG. 1. This AGC approach maintains consistent RF channel level between bands. Thus, changes in the number of channels carried by the bands do not affect the channel levels in the different bands.

Although the present invention has been described in connection with preferred embodiments, it will be apparent that numerous adoptions and modifications may be made thereto without departing from the spirit and scope of the invention, as set forth in the following claims.

We claim:

1. A transmitter for use in a fiber communications system, comprising:
- an input terminal for receiving a composite electrical signal;
- a first level setting circuit for variably setting a level of the composite electrical signal supplied to said input terminal;
- a second level setting circuit for variably setting a level of a composite electrical signal output by said first level setting circuit;
- a laser responsive to a composite electrical signal output by said second level setting circuit for outputting a modulated optical signal corresponding to the composite electrical signal supplied to said input terminal;
- detecting means for detecting the composite electrical signal output by said second level setting circuit and outputting a control signal based on a composite level of the detected electrical signal; and
- adjusting means responsive to the control signal for adjusting said first and second level setting circuits.

2. The transmitter in accordance with claim 1, wherein said first and second level setting circuits comprise attenuation circuits.

3. The tranmsitter in accordance with claim 1, wherein said first and second level setting circuits comprise pin attenuators.

4. The transmitter in accordance with claim 3, wherein said pin attenuators each comprise a bridged T-network.

5. The transmitter in accordance with claim 1, further comprising:
- a first amplifier connected between said first and second level setting circuits for amplifying the composite electrical signal output by said first level setting circuit; and
- a second amplifier connected between said second level setting circuit and said laser for amplifying the composite electrical signal output by said second level setting circuit.

6. The transmitter in accordance with claim 1, wherein said detecting means comprises:
- detector diodes for detecting the composite electrical signal output by said second level setting circuit;
- a comparator for comparing the detected signal received at a first input with a reference signal received at a second input and outputting signals corresponding to changes in a level of the detected signal;
- an integrator for integrating the signals output by said comparator; and
- amplifying means for amplifying the integrated signals to generate the control signal.

7. The transmitter in accordance with claim 1, further comprising:
- means, responsive to a user setting, for generating a user signal supplied to the first input of said comparator to thereby generate a control signal for adjusting said first and second level setting circuits; and
- a switch for selectively providing the user signal or the detected signal to the first input of said comparator.

8. The transmitter in accordance with claim 7, wherein said means responsive to a user setting comprises a potentiometer.

9. The transmitter in accordance with claim 1, wherein said adjusting means comprises a first adjusting circuit responsive to the control signal for adjusting the level set by said first level setting circuit and a second adjusting circuit responsive to the control signal for adjusting the level set by said second level setting circuit.

10. The transmitter in accordance with claim 1, wherein the received composite electrical signal is a CATV signal.

11. A receiver for use in a fiber communications system, comprising:
- a photodetector for converting a received optical signal to a composite electrical signal;
- a variable gain amplifier for variably amplifying the composite electrical signal output by said photodetector;

a level setting circuit for variably setting a level of a composite electrical signal output by said variable gain amplifier;

an output terminal for outputting a composite electrical signal output by said level setting circuit as an output composite electrical signal corresponding to the received optical signal;

detecting means for detecting the composite electrical signal output by said level sitting circuit and outputting a control signal based on a level of a pilot portion of the detected electrical signal; and

adjusting means responsive to the control signal for adjusting said variable gain amplifier and said level setting circuit.

12. The receiver in accordance with claim 11, wherein said variable gain amplifier comprises a variable gain transimpedance amplifier.

13. The receiver in accordance with claim 11, wherein said level setting circuit comprises an attenuation circuit.

14. The receiver in accordance with claim 11, wherein said level setting circuit comprises a pin attenuator.

15. The receiver in accordance with claim 11, wherein said adjusting means comprises a first adjusting circuit for generating a first signal to adjust the gain of said variable gain amplifier and a second adjusting circuit for generating a second signal to adjust the level set by said level setting circuit.

16. The receiver in accordance with claim 15, wherein said first adjusting circuit adjusts the gain of said variable gain amplifier while the level set by said level setting circuit is constant.

17. The receiver in accordance with claim 15, wherein said second adjusting circuit adjusts the level set by said level setting means while the gain of said variable gain amplifier is constant.

18. The receiver in accordance with claim 11, wherein said detecting means comprises:

a filter for filtering the pilot portion from the composite electrical signal output by said level setting circuit.

19. The receiver in accordance with claim 18, wherein said detecting means further comprises:

a detector for generating an envelope signal proportional to the envelope of the pilot portion of the composite electrical signal output by said level setting circuit;

a peak detector for generating an output signal proportional to the peak of the envelope signal;

an integrator for integrating the output signal of said detector to provide the control signal.

20. The receiver in accordance with claim 19, further comprising:

means, responsive to a user setting, for generating a control signal for adjusting said variable gain amplifier and said level setting circuit; and

a switch for selectively providing the user control signal or the output of said integrator to said adjusting means.

21. The receiver in accordance with claim 19, wherein said adjusting means comprises:

a first adjusting circuit responsive to the control signal for adjusting the gain of said variable gain amplifier; and

a second adjusting circuit responsive to the control signal for adjusting the level set by said level setting circuit.

22. The receiver in accordance with claim 21, wherein the control signal output by said detecting means varies from a first to a second voltage and wherein

said first adjusting circuit adjusts the gain of said variable gain amplifier from an initial value to a minimum value when the control signal varies from the first voltage to a third voltage intermediate the first and second voltages; and

said second adjusting circuit adjusts the level set by said level setting circuit from a minimum attenuation to a maximum attenuation when the control signal varies from the third voltage to the second voltage.

23. The receiver in accordance with claim 22, wherein the gain of said variable gain amplifier remains at the minimum value when the control signal varies from the third voltage to the second voltage and the attenuation of said level setting circuit remains at the minimum attenuation when the control signal varies from the first voltage to the third voltage.

24. A receiver for a fiber communications system comprising first and second receiving units for receiving respective optical signals and outputting respective composite electrical signals and a combiner for combining the outputs of said first and second receiving units into a single output composite electrical signal, each of said first and second receiving units comprising a photodetector for converting a received optical signal to a composite electrical signal, a variable gain amplifier for variably amplifying the composite electrical signal output by said photodetector, a level setting circuit for variably setting a level of a composite electrical signal output by said variable gain amplifier, detecting means for detecting the composite electrical signal output by said level setting circuit and outputting a control signal based on a level of a pilot portion of the detected electrical signal, and adjusting means responsive to the control signal for adjusting said variable gain amplifier and said level setting circuit.

25. A fiber optics communications system, comprising:

a transmitter for transmitting an optical signal, said transmitter comprising:

an input terminal for receiving a composite electrical signal;

level setting circuitry for variably setting a level of the composite electrical signal supplied to said input terminal;

a laser responsive to a composite electrical signal output by said level setting circuitry for outputting a modulated optical signal corresponding to the composite electrical signal supplied to said input terminal;

detecting means for detecting the composite electrical signal output by said level setting circuitry and outputting a control signal based on a composite level of the detected electrical signal; and

adjusting means responsive to the control signal for adjusting said level setting circuitry; and

a receiver for receiving the optical signal transmitted by said transmitter, said receiver comprising:

a photodetector for converting the received optical signal to a composite electrical signal;

level setting circuitry for variably setting a level of a composite electrical signal output by said photodetector;

an output terminal for outputting a composite electrical signal output by said level setting circuitry as an output composite electrical signal corresponding to the received optical signal;

detecting means for detecting the composite electrical signal output by said level setting circuitry and outputting a control signal based on a level of a pilot portion of the detected electrical signal; and

adjusting means responsive to the control signal for adjusting said level setting circuitry.

26. A transmitter for use in a fiber communications system, comprising:

an input terminal for receiving a composite electrical signal;

a first level setting circuit for variably setting a level of the composite electrical signal supplied to said input terminal;

a first amplifier for amplifying an output signal of said first level setting circuit;

a second level setting circuit for variably setting a level of an output signal of said first amplifier;

a second amplifier for amplifying an output signal of said second level setting circuit;

a laser responsive to a signal output by said second amplifier for outputting a modulated optical signal corresponding to the received composite electrical signal;

detecting means for detecting the signal output by said second amplifier and outputting a control signal based on a level of the detected signal; and

adjusting means responsive to the control signal for adjusting said first and second level setting circuits.

27. The transmitter in accordance with claim 26, wherein said detecting means detects the composite electrical signal output by said second amplifier and outputs a control signal based on a composite level of the detected electrical signal.

28. A receiver for use in a fiber communications system, comprising:

a photodetector for converting a received optical signal to a composite electrical signal;

a first variable gain amplifier for amplifying the composite electrical signal output by said photodetector;

a level setting circuit for setting a level of an output signal of said variable gain amplifier;

a second amplifier for amplifying an output signal of said level setting circuit;

an output terminal for outputting a signal output by said second amplifier;

detecting means for detecting the signal output by said second amplifier and outputting a control signal based on a level of a pilot portion of the detected signal; and

adjusting means responsive to the control signal for adjusting said variable gain amplifier and said level setting circuit.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,267,071

DATED : November 30, 1993

INVENTOR(S) : Frank R. LITTLE et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 14,

Claim 7, line 1, change "claim 1" to --claim 6--.

Signed and Sealed this

Twenty-first Day of November, 1995

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks